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Investigating Human Exposure to Contaminants in the Environment:

A Handbook for Exposure Calculations

Canada

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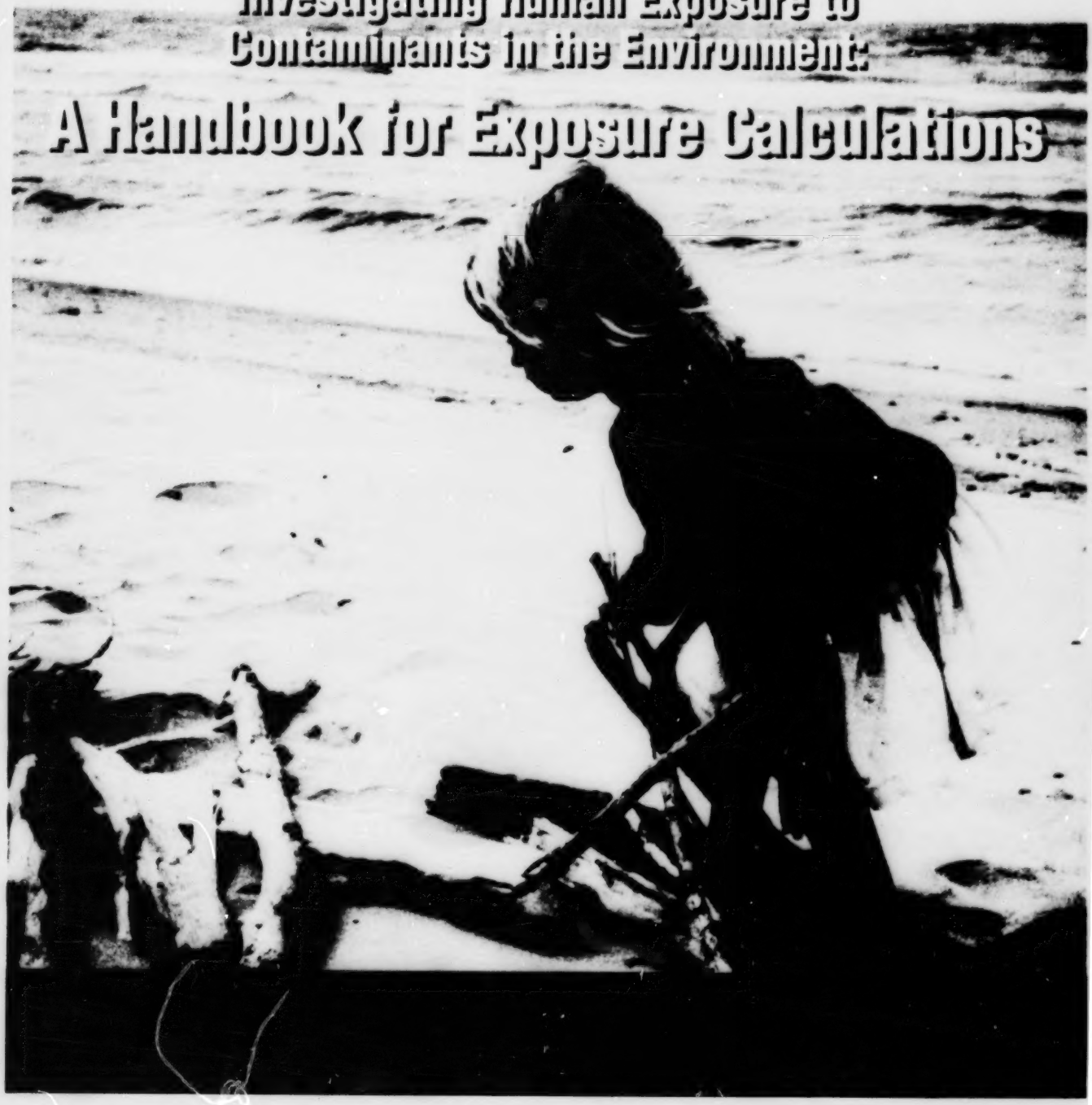

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Health Canada

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FOREWORD

People and communities are becoming more aware of the relationship between their health and the environment. *Investigating Human Exposure to Contaminants in the Environment* consists of two handbooks that provide information to assist communities in understanding this relationship. *A Community Handbook* will help you carry out a descriptive exposure assessment and develop a health profile of your community. *A Handbook for Exposure Calculations* describes the general methods followed for calculating human exposure to environmental contaminants. These handbooks have been prepared by the Great Lakes Health Effects Program of the Health Protection Branch, Health Canada.

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1. ABOUT THIS HANDBOOK

Why Was This Handbook Developed?

In recent years, there has been a tremendous increase in people's awareness of environmental issues and a growing concern over how their health is affected by their environment. Health professionals who respond to public demands need more tools to help them assess the risks posed by environmental contaminants in their communities. The public, on the other hand, want to know how these assessments are done.

Radionuclide

An unstable nuclide (nucleus of an atom) that undergoes spontaneous radioactive decay, emitting ionizing radiation as it does so, and changing eventually from one element into another.

This handbook describes a step-by-step process for calculating exposures to **chemicals and radionuclides** present in the environment. The methods presented in this handbook may be of use to health professionals performing exposure assessments. This information may also help the public understand the process and methods generally followed for performing exposure assessments.

What Is in This Handbook?

This handbook provides the technical information necessary for calculating exposure to environmental contaminants. It includes a brief description of the exposure model and the general method used to estimate exposure to contaminants. Equations used to calculate exposure, along with specific examples showing how the calculations are performed, are included. To solve the equations, numerous measurements and values are needed. Because all of these values may not be available for your situation, the handbook contains tables of standard values that can be substituted instead.

How Can the Results Be Used?

What can you do with the results of the calculations described in this handbook? Firstly, your results will help identify which exposure pathways are important for each contaminant of concern in your community. Knowledge of the main exposure pathways can be useful in designing strategies to reduce exposure. The

results of exposure calculations can also help to determine whether more detailed studies are necessary before actions to reduce exposure are taken.

A Word of Caution

Many assumptions and judgements are made when calculating people's exposure to environmental contaminants. Some of these include using average values for body weight, the amount of food and water people consume, the amount of air people breathe, and the number of times people are exposed to contaminants over their lifetime. Different groups performing the same calculations may use different assumptions or have more or less information to work with. Therefore, the results obtained by one group or agency may be different from the results of others.

This handbook is not intended as a substitute for professional expertise. Instead, it describes the general approach taken in estimating exposure to environmental contaminants. If you want to calculate exposures in your community, be sure to consult with professionals whenever you feel unsure about gathering and analysing data, drawing conclusions and making recommendations.

Radioactive elements (radionuclides) decay or break down into lighter substances. As they decay, they emit energy which is called ionizing radiation. The more decay, the more radiation is produced. The energy released during radioactive decay is in the form of alpha, beta, or gamma radiation. The ***activity*** *of a radionuclide is a measure of its rate of decay. The becquerel (Bq) is the International System (S.I.) unit for measuring this activity. The older unit of measurement is the curie (Ci). One curie equals 3.7 x 10^{10} becquerels.*

Units of Measurement for Contaminants in the Environment – Terminology

The concentrations of chemicals and radionuclides can be expressed in many ways using different units of measurements. When calculating exposure, it may be necessary to convert contaminant concentrations from one unit to another.

In *liquids* such as water, chemical contaminants are most commonly expressed in milligrams per litre (mg/L) or micrograms per litre (µg/L). One milligram equals one thousand micrograms. Similarly, radionuclide activity concentrations are expressed in becquerels per litre (*Bq*/L). In *soil, food and other solids*, chemical contaminant levels are usually expressed in milligrams per kilogram (mg/kg) while radionuclide activity concentrations are expressed in becquerels/kilogram (*Bq*/kg). Concentrations of chemicals and particulates in *air* are usually expressed as milligrams or micrograms per cubic metre (mg/m^3, µg/m^3) or as becquerels per cubic metre (*Bq*/m^3) for radionuclide activity. Occasionally, the units for chemical and radionuclide concentrations in water, soil, food, and air are expressed in parts per million (ppm), parts per billion (ppb), parts per trillion (ppt) or parts per quadrillion (ppq). The relationship of the various expressions of concentration are shown on the opposite page.

BASIC UNITS			
g (gram)		µg (microgram)	= 10^{-6} gram
kg (kilogram)	= 10^{3} gram	ng (nanogram)	= 10^{-9} gram
mg (milligram)	= 10^{-3} gram	pg (picogram)	= 10^{-12} gram

The basic unit for radionuclide activity is the becquerel (*Bq*).

SOIL AND WATER

Metric Units in Liquids*	Equivalent in Parts Per Unit				Metric Units in Solids*
	ppm	ppb	ppt	ppq	
1 g/L	10^{3}	10^{6}	10^{9}	10^{12}	1 g/kg
1 mg/L	1	10^{3}	10^{6}	10^{9}	1 mg/kg
1 µg/L	10^{-3}	1	10^{3}	10^{6}	1 µg/kg
1 ng/L	10^{-6}	10^{-3}	1	10^{3}	1 ng/kg
1 pg/L	10^{-9}	10^{-6}	10^{-3}	1	1 pg/kg

* The radionuclide activity concentration is usually expressed as *Bq*/L in liquids and *Bq*/kg in solids.

AIR

Converting from ppm in Air to its Equivalent in µg/m³

Converting air contaminant values from ppm to µg/m³ is not as straightforward as similar conversions in water or soil. In this case, the conversion is dependent on the atomic molecular weight of the contaminant. Atomic weights are found in most chemistry textbooks. To convert from ppm to µg/m³ in air, the following equation is used:

Contaminant Concentration (µg/m³) = Contaminant concentration (ppm) x Molecular Weight of the Contaminant x 40.9

EXAMPLE: Convert the pollutant ozone, at 0.08 ppm in air, to its equivalent in µg/m³. The molecular weight of ozone is 48.

Contaminant Concentration (µg/m³) = 0.08 ppm x 48 x 40.9

= 157 µg/m³

157 µg/m³ ozone is equivalent to 0.08 ppm ozone

The radionuclide activity concentration in air is usually expressed as *Bq*/m³.

2. THE EXPOSURE MODEL

What Is Exposure?

Exposure is any contact between a substance and an individual who has touched, breathed dust or fumes, or swallowed material or liquid from a contaminated source. Contaminants must follow pathways from the point of release into the environment to the point of contact with humans in order for exposure to take place.

What Is an Exposure Pathway?

An **exposure pathway** describes how a contaminant travels through the environment from its source to humans or other living organisms. An exposure pathway consists of the five following elements:

- source of contamination;
- environmental media;
- point of exposure;
- receptor person or population; and
- route of exposure.

Source of Contamination

Sources of environmental contaminants are numerous and vary between communities. They can include exhaust from cars, emissions from smokestacks, wastewater released by factories and mills, waste disposal sites, closed factories and storage sites, consumer products (e.g., paints, household cleaning products) and numerous other sources, both indoors and outdoors. A number of substances are also released into the environment from natural sources.

Environmental Media

Once released from its source, a contaminant will travel through environmental media to points where human exposure can occur. In humans, the major environmental media include water, air, food, and soil:

i. WATER

Groundwater (water below ground, such as from aquifers and wells)

- drinking water from wells (municipal or domestic), bathing, showering;
- industrial, agricultural or recreational use of groundwater; and
- recreational and other use of natural springs and sink holes.

Surface water (water from lakes, rivers, and ponds)

- drinking water (municipal or domestic), bathing, and showering;
- recreation, such as boating, canoeing, and swimming; and
- industrial or agricultural use.

ii. AIR

- indoor air, including air quality at home, work and school;
- outdoor air; and
- contaminant gases from industrial production or other processes (e.g., car exhaust, home heating).

iii. FOOD

- foods grown with contaminated water or grown in areas where the soil is contaminated. This would include food grown for personal consumption;
- contaminated fish and wildlife;
- foods containing pesticide residues;
- foods packaged in containers which contaminate the contents (e.g., lead-soldered cans used in some imported goods); and
- mother's milk (for nursing infants) where the mother has been exposed to chemicals which accumulate in fat in tissues (breast milk has a high fat content).

iv. SOIL

- bare ground (exposure of workers to soil, swallowing soil or skin contact with soil);
- contaminated soil blown as dust in the air and particles deposited on other surfaces (such as food);
- soil below the surface (workers involved in digging and excavating); and
- contaminated sediments at the bottom of lakes, rivers, and ponds.

Point of Exposure

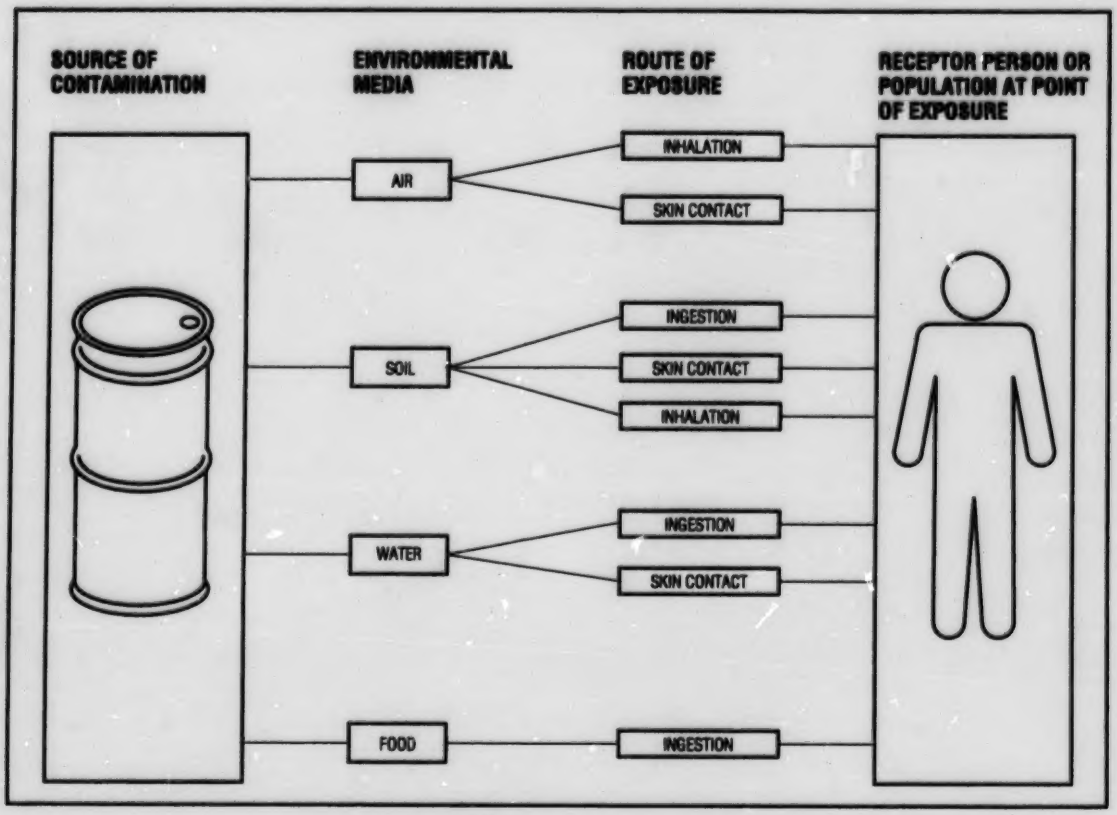
The point of exposure is the location where contact with a contaminant occurs. For example, people can be exposed to contaminants in the home, a business, a playground, a lake, river or other body of water.

Receptor Person or Population

The receptor person or population is the one exposed to the contaminant at the point of exposure. For example, swimmers may be exposed while bathing in a contaminated river; anglers may be exposed by consuming contaminated sport-caught fish.

FIGURE 1:

Major Pathways of Human Exposure to Environmental Contaminants



Routes of Exposure

An **exposure route** is how a contaminant enters the human body. There are three general routes by which humans may take contaminants into their bodies. These include:

i. Ingestion

- Swallowing something containing the contaminant. This can include food, water, small amounts of soil, and accidental ingestion of objects or other liquids containing the contaminant. The mouth, throat, stomach, and intestines can absorb certain ingested materials rapidly.

ii. Inhalation

- Breathing in a substance as a gas or vapour, or as airborne particles. This includes small amounts of soil and dust that can be inhaled into the lungs. The lungs often absorb gases and vapours quickly and efficiently.

iii. Skin Contact

- Some contaminants in water, soil and air can be absorbed through the skin.

In addition to the above three exposure routes, exposure to ionizing radiation (from radionuclides on the ground, in the air, or from radiation sources outside the body) may also occur by direct external irradiation.

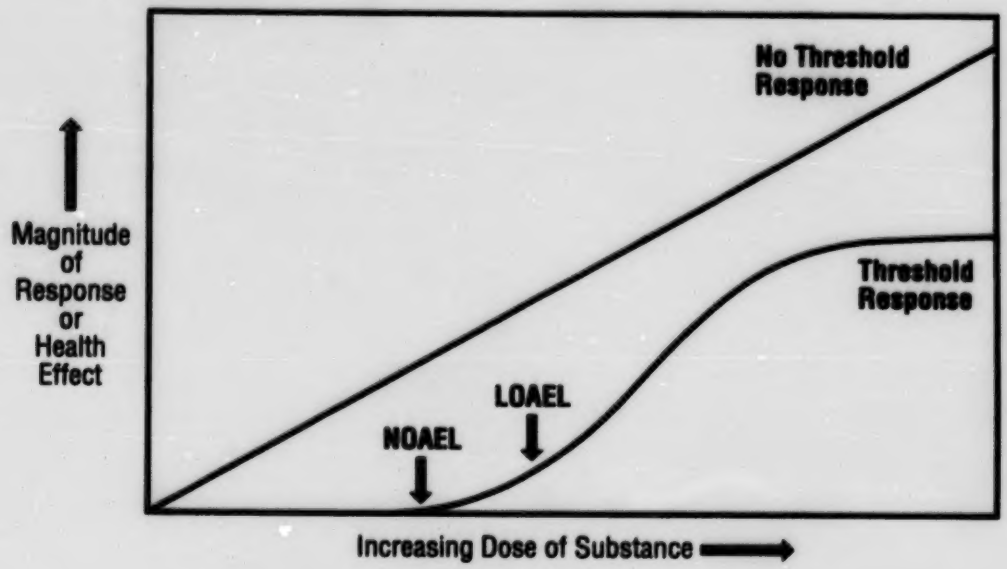
The elements of an exposure pathway are shown in FIGURE 1.

What is the Dose-Response Relationship?

The relationship between the amount of a contaminant that is given (the dose) and the health effect (the response) is referred to as the dose-response relationship. Dose-response relationships are usually determined in laboratory experiments using animals and, in some instances, from results of epidemiological studies in humans.

FIGURE 2:

Dose-Response Relationship



NOAEL - No Observed Adverse Effect Level - The level of exposure to a chemical at which no adverse effects are observed during studies with laboratory animals or in human epidemiological studies.

LOAEL - Lowest Observed Adverse Effect Level - The lowest level of exposure to a chemical at which adverse effects are observed during studies with laboratory animals or in human epidemiological studies.

For most contaminants, no adverse health effects can be observed when the dose falls below a certain level. This level is called the threshold dose. Whether or not adverse health effects occur below the threshold cannot be known conclusively because of the limitations of toxicological studies.

Based on the knowledge of how cancer develops, it is generally assumed that contaminants which cause cancer (carcinogens) can potentially do so even at the very lowest levels of exposure. In other words it is assumed that most carcinogens have no threshold concentration. A typical dose-response relationship for carcinogens is shown by the straight line titled "No Threshold Response" in FIGURE 2.

For health effects other than cancer, it is assumed that the health effect will not occur when the dose of the contaminant falls below a certain threshold. A typical dose-response relationship for such contaminants is shown by the curved line titled "Threshold Response" in FIGURE 2.

3. ESTIMATING EXPOSURE TO CHEMICALS

What is the Estimated Daily Intake (EDI)?

We are all exposed to a low level of contamination in the air we breathe, in the food we eat, and in the water we drink. The Estimated Daily Intake (EDI) for a chemical contaminant represents the total exposure from all known or suspected exposure pathways for an average person. Examples of how to calculate the EDI are shown in Section 6 - Estimated Daily Intake: Equations and Examples.

CALCULATING THE ESTIMATED DAILY INTAKE

Estimated Daily Intake (EDI) of a chemical can be calculated by adding up all the exposures from various pathways. The EDI of one contaminant can be represented by the following equation:

$$EDI = ED_a + ED_w + ED_s + ED_f + ED_{ws} + ED_{ss}$$

Each ED (Estimated Dose) is the amount of the contaminant taken in through a different combination of exposure pathway and exposure route. Specifically:

ED_a is the amount inhaled through the air,

ED_w is the amount taken in by drinking water,

ED_s is the amount taken in by eating soil,

ED_f is the amount taken in with food,

ED_{ws} is the amount absorbed through skin contact with water,

ED_{ss} is the amount absorbed through skin contact with the soil.

To calculate the estimated amount of the contaminant taken in through these combinations of exposure pathway and route requires a different equation for each combination. However, all the equations are somewhat similar. The general equation for each estimated dose is:

$$ED = \frac{C \times CR \times EF}{BW}$$

where,

ED = Estimated Dose — is generally the number of milligrams of the contaminant that enter the body for each kilogram of body weight (mg / kg /day).

C = Concentration of the contaminant in the exposure pathway being considered.

CR = Contact Rate: — The amount of water, food, air, etc., which is swallowed, inhaled or comes into contact with the skin in one day. Typical units for food eaten are grams per day (g / day).

EF = Exposure Factor: — This number indicates how often the individual is exposed during a year and the number of years that this pattern has been repeating itself. This factor is needed especially when exposure does not occur daily, such as exposures at work (only five days a week) or exposures related to seasonal activities (swimming in the summer in contaminated water).

BW = Body Weight: — The average body weight of an individual in kilograms (kg).

What is the Tolerable Daily Intake (TDI)?

The tolerable daily intake (TDI) is an estimate of the quantity of a non-cancer causing chemical that humans can be exposed to every day for their whole life without threatening their health. The TDI can also apply to the non-cancer effects of chemicals which cause cancer. It is usually expressed in milligrams of chemical per kilogram of body weight per day (mg/kg/day). The term "acceptable daily intake" (ADI) has also been used instead of TDI. However, the two terms describe the same value.

TDIs for humans are usually based on studies carried out on laboratory animals. In these studies, researchers establish what is called the No Observed Adverse Effect Level (NOAEL), where the concentration of the chemical does not lead to any adverse health effects in animals, or the Lowest Observed Adverse Effect Level (LOAEL) which is the lowest concentration of contaminant at which adverse health effects are observed. This level is then divided by an uncertainty factor (UF) to calculate the TDI. Depending on how exhaustive the studies have been, how confident the researchers are in transferring their conclusions to humans, and the adverse effects that the substance can cause, the uncertainty factor may range from 10 to several thousand.

$$TDI = \frac{NOAEL\ (LOAEL)}{UF}$$

TDIs are used by governments to establish guidelines to protect human health from the potential health effects of exposure to environmental contaminants. These guidelines are reviewed and revised periodically, especially when new scientific information is obtained. As a result of new information, or of different ways of estimating NOAEL, LOAEL and UF, different governments may set different Tolerable Daily Intake levels.

THE UNCERTAINTY FACTOR

The uncertainty factor (UF), also known as the safety factor, reflects the uncertainty associated with the variety of scientific data used to estimate the TDI. An uncertainty factor of 10 is used when TDIs are based on epidemiological studies of prolonged exposure of healthy humans or when no serious adverse effects are known to occur. This factor accounts for differences in people's sensitivity to contaminants. If the TDI is not based on studies of prolonged human exposure, this basic UF of 10 is multiplied by another 10 for each of the following conditions that apply:

- When TDIs are based on experimental studies using long-term exposure to laboratory animals. This factor accounts for the uncertainty involved in applying animal data to humans.
- When TDIs are based on scientific studies using shorter exposures of the animals to the contaminants. This factor accounts for the uncertainty in extrapolating from short-term to long-term exposures.
- When TDIs are based on a LOAEL rather than a NOAEL. This factor accounts for the uncertainty in calculating NOAELs from LOAELs.
- Additional uncertainty factor (up to 10, and in some cases greater than 10) may be applied depending on the seriousness of the adverse health effect observed.

What is the Risk-specific Dose?

A different approach than the Tolerable Daily Intake is required for contaminants known to cause cancer. This is because there may be no level of exposure to these contaminants that does not present any risk to health. In these cases, "zero risk" can be achieved only by eliminating all possible human exposure. However, this may not be possible with many contaminants, such as naturally occurring carcinogens that may be widespread in the environment. Therefore, it is desirable to reduce exposure to carcinogens to as low a level as possible, while recognizing that "zero" exposure is impossible.

For such substances, a decision must be made as to how large a risk of cancer can be accepted, in order to set acceptable intake levels. Various acceptable levels of risk are currently being used around the world, depending on specific circumstances. Such levels often vary between one extra cancer death per 10,000 people exposed (1×10^{-4}) to the contaminant over their entire lifetime, to one extra cancer death per million people exposed (1×10^{-6}).

Once an acceptable level of risk (R) has been established, it is divided by a factor (known as the Slope Factor: SF), which has been determined from the results of laboratory and epidemiological studies, to obtain a Risk-specific Dose (RsD). The Risk-specific Dose is the amount of contaminant that people can be exposed to on a daily basis, over their entire lifetime, that will not exceed the accepted level of risk of cancer. It is usually expressed in milligrams of chemical per kilogram of body weight per day (mg/kg/day).

$$RsD = \frac{R}{SF}$$

Example: Calculate the Risk-specific Dose (RsD) for a contaminant known to cause cancer. The Slope Factor* (SF) for this contaminant is 4.3×10^{-3} $(mg/kg/day)^{-1}$ and the accepted level of risk (R) is one extra cancer death per year per one million people exposed (10^{-6}).

$$RsD = \frac{1 \times 10^{-6}}{4.3 \times 10^{-3}\ (mg/kg/day)^{-1}}$$

$$= 2.3 \times 10^{-4}\ mg/kg/day$$

* *Slope Factors (SF) can be obtained from on-line toxicological databases such as the Integrated Risk Information System (IRIS) available from the United States Environmental Protection Agency. The IRIS registry contains regulatory information on more than 400 chemicals with more added to the database each year. IRIS is available in disc format for use on microcomputers.*

How Does EDI Compare with TDI or RsD?

Once an EDI has been calculated for a contaminant, it is then compared to the TDI or to the RsD, depending on whether it is a non-carcinogen or a carcinogen. As a general rule, if the TDI or RsD is exceeded, exposure to the contaminant is a potential health concern. In some instances, additional medical and toxicological information may indicate that exposures exceeding the TDI or RsD are not a health concern. In other instances, exposures below the TDI or RsD could be a health concern because of interactions between chemicals or because certain individuals in the exposed population are more sensitive. Therefore, it should be recognized that the TDI and RsD are estimates of exposures at which adverse health effects are not expected to occur for the majority of the population. They do not describe a level at which we are absolutely certain that no risk to health will occur for every individual. TDIs and RsDs for a number of environmental contaminants are shown in TABLE 6.

COMPARING EDI TO TDI OR RsD

Non-carcinogens

- If the EDI is well below the TDI, it indicates that exposure to that contaminant likely does not pose a significant risk to human health.
- As the EDI approaches the level of the TDI, the concern regarding the risk to human health increases.
- If the EDI is above the TDI, then exposure and potential risk to people's health should be considered important. Action may be necessary to reduce the exposure.

Carcinogens

- If the EDI is well below the RsD, it indicates that the risk of cancer from exposure to that contaminant is minimal for that situation.
- As the EDI approaches the RsD, the concern regarding the risk to human health increases.
- If the EDI is above the RsD, then exposure and potential risk to human health should be considered important. Action may be necessary to reduce the exposure.

4. ESTIMATING EXPOSURE TO IONIZING RADIATION

What Are the Differences between Radiation and Chemical Exposure Estimates?

Calculations of exposure to ionizing radiation are treated somewhat differently than chemical contaminants. Because the effects of radiation exposure are well understood, radiation experts express dose in a unit called the sievert (*Sv*), which is a measure of the total harm that may be caused in a human exposed to ionizing radiation from any radiation source. Unlike chemical contaminants, it is the total exposure from all sources that is controlled, rather than the exposure from individual radionuclides. This is done since it is the total exposure that determines the risk of a health effect occurring.

Furthermore, the dose rate is expressed on a yearly basis, rather than a daily basis. This dose is calculated to include all direct **external** irradiation received in the year, and the dose that will continue to be received **internally** from all radionuclides ingested or inhaled in the current year. The period over which this extended dose, due to internal radiation, is calculated has been standardised to 50 years for exposures in adults (18 years of age and older) and 70 years for exposures in children (under 18 years of age). Unlike the approach taken for chemical contaminants, this approach accounts for the radiation dose that will continue to be received from radionuclides that are retained in the body.

How Is Radiation Measured?

External irradiation can be measured directly using appropriate instrumentation. In order to calculate the extended **internal** dose, conversion factors are required to convert from the amount of radionuclide taken into the body, in becquerels, to a dose in sieverts, or millisieverts (*mSv*). These dose conversion factors (DCFs) have been calculated by the National Radiation Protection Board (NRPB). DCFs exist for all radionuclides, and therefore the total dose that will be received from all radionuclides taken into the body in a year can be calculated. It is this total dose, rather than the dose from an individual radionuclide, that is important.

Calculating the Estimated Dose for Exposure to Ionizing Radiation

The Estimated Dose (ED) for exposure to ionizing radiation can be calculated by adding up all exposures received in a year from various pathways and can be represented by the following equation:

$$ED = ED_{external} + ED_{internal}$$
$$= ED_{external} + ED_{a} + ED_{w} + ED_{s} + ED_{f}$$

$ED_{external}$ is the direct external irridiation received in a year. $ED_{internal}$ is the dose that will be received over the next 50 years (adults) or 70 years (children), from all radionuclides taken into the body in the current year, specifically:

ED_a is the estimated committed dose from radionuclides inhaled through the air,

ED_w is the estimated committed dose from radionuclides taken in by drinking water,

ED_s is the estimated committed dose from radionuclides taken in by eating soil,

ED_f is the estimated committed dose from radionuclides taken in by eating food.

To calculate the estimated committed dose from internal radionuclides, an equation of the following general form is used for each radionuclide for each pathway:

$$ED_x = C \times CR \times CF \times EF \times DCF$$

where,

ED_x = Estimated Committed Dose over 50 years (adults) or 70 years (children) from a specific radionuclide taken into the body in the current year (*Sv*) for a specific pathway "x" (air inhalation, and water, soil or food ingestion).

C = Concentration of the radionuclide in the exposure pathway being considered (e.g., *Bq*/L for radionuclides in water).

CR = Contact Rate: The amount of water, food, air, etc., which is taken into the body in one day. Typical units for food are grams per day (g / day) and litres per day (L / day) for water.

CF = Conversion Factor: The factor of 365 days is required to convert the Contact Rate (CR) from units/day to units/year.

EF = Exposure Factor: This factor indicates how often the individual is exposed during a year. It is needed especially when exposure does not occur daily, such as at work (only five days a week) or when related to seasonal activities (swimming in the summer).

DCF = Dose Conversion Factor: This factor converts the amount of radionuclide taken into the body via inhalation or ingestion, in becquerels, to the extended 50-year (adults) or 70-year (children) dose in sieverts. DCFs are usually expressed as *Sv*/*Bq*.

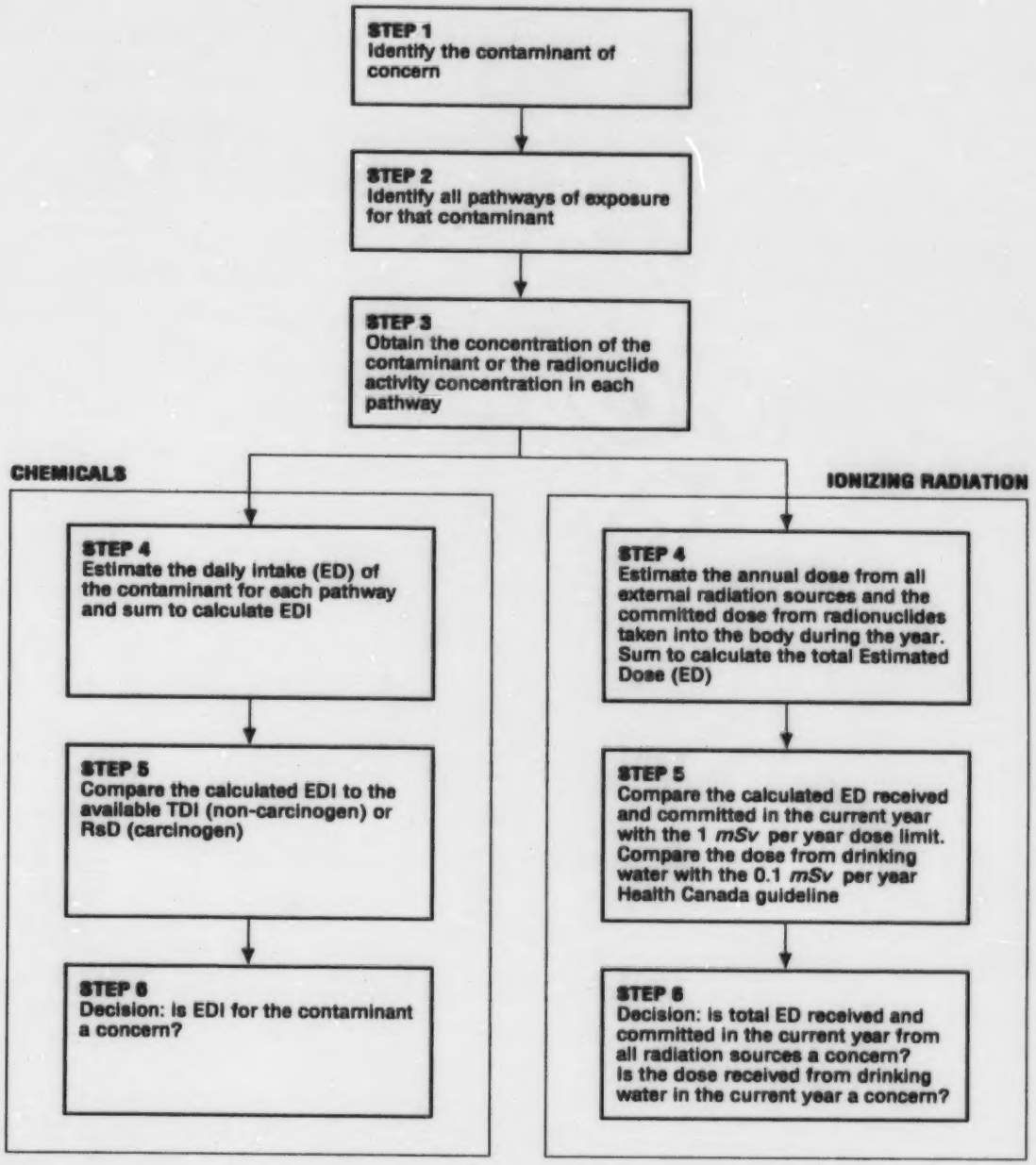
What Are the Recommended Limits to Radiation Exposure?

Dose limits for radiation exposure, from artificial sources, for the public have been issued by the International Commission on Radiological Protection (ICRP), and have been set at 1 *mSv* per year. Implicit in this limit is the understanding that exposures must be as low as reasonably achievable. This limit is in the process of being adopted by the Atomic Energy Control Board (AECB) of Canada. It applies to the total dose received from all internal and external sources, but does not include the natural background radiation that everyone is exposed to or exposures received for medical purposes. Actual doses received by the public from artificial sources are much lower than this limit. Artificial sources include levels of natural radionuclides that have been enhanced due to human practices such as uranium mining. In addition, the total dose at the site boundary of nuclear facilities may not exceed 0.05 *mSv* in a year as stipulated by the AECB. By comparison, the dose received from the natural background radiation is about 3 *mSv* per year.

Health Canada has issued guidelines for radionuclides in drinking water. The total dose received from the consumption of drinking water should not exceed 0.1 *mSv* per year, and this includes the dose from all radionuclides that exist naturally in the environment, as well as those that are artificial. This level of dose corresponds to a theoretical risk of about five extra cancer deaths per million people exposed.

5. THE STEP-BY-STEP APPROACH FOR ESTIMATING EXPOSURE TO ENVIRONMENTAL CONTAMINANTS

This handbook focuses on steps four, five and six - calculating the Estimated Daily Intake of chemicals and the total Estimated Dose of radiation - of the following flow chart. For more information on steps one through three, see the companion "Community Handbook".


STEP 1
Identify the contaminant of concern
STEP 2
Identify all pathways of exposure for that contaminant
STEP 3
Obtain the concentration of the contaminant or the radionuclide activity concentration in each pathway
CHEMICALS
STEP 4
Estimate the daily intake (ED) of the contaminant for each pathway and sum to calculate EDI
STEP 5
Compare the calculated EDI to the available TDI (non-carcinogen) or RsD (carcinogen)
STEP 6
Decision: is EDI for the contaminant a concern?
IONIZING RADIATION
STEP 4
Estimate the annual dose from all external radiation sources and the committed dose from radionuclides taken into the body during the year. Sum to calculate the total Estimated Dose (ED)
STEP 5
Compare the calculated ED received and committed in the current year with the 1 mSv per year dose limit. Compare the dose from drinking water with the 0.1 mSv per year Health Canada guideline
STEP 6
Decision: is total ED received and committed in the current year from all radiation sources a concern? Is the dose received from drinking water in the current year a concern?

6. ESTIMATED DAILY INTAKE FOR CHEMICALS: EQUATIONS AND EXAMPLES

This section describes how to carry out the calculations for the Estimated Daily Intake of a chemical contaminant. It also gives advice on what values to use in the equations and includes tables of average values that can be used when you have no specific, local information available.

The equations and calculations in this section can be onerous. Consult an experienced scientist for help.

Assumptions and Inferences

Many subjective judgements are made in the process of calculating exposures using the many precise formulas available. This happens because some of the information for equations is not available, or values that are available do not accurately reflect the real variations in areas such as the concentration of contaminants in the air, soil, water and food. Many of the assumptions and judgement calls that may be made during an exposure assessment are highlighted below:

- How should the movement of contaminants through the environment be predicted? A specific example of this question is: How should the dispersion of air pollutants in the atmosphere due to wind currents be predicted?
- How should the size and nature of the population potentially exposed to the contaminant be estimated? Can the exposure measurements taken from a small segment of the community be applied to the entire community and, if so, how should this done?
- How should patterns of human activity, such as variations in diet, lifestyle and hobbies, be taken into account?
- How should differences in exposure to the contaminant, such as timing, duration and age at first exposure, be estimated?
- How should the breathing rate, water and food consumption, body weight and surface area of the potentially exposed population be estimated?
- How should exposures of special risk groups, such as pregnant women and small children, be estimated?

It is important that the units of measurement used in the equations be compatible when calculating exposures.

Because these judgement calls often change the results of an exposure assessment, it may be necessary to seek professional advice before performing these calculations.

Exposure Factors

The exposure factor is a value that must be calculated in each of the examples that follow. Its calculation also involves a judgement call.

Exposure to contaminants may occur intermittently or not necessarily on a daily basis. In these cases, an exposure factor (EF) can be calcu-

lated to estimate an average dose over the exposure period. The exposure factor is calculated by multiplying the number of days in the year on which exposure occurs by the number of years that this pattern has been repeating itself. This number is then divided by the time period over which the dose is to be averaged. For example, if a child comes into contact with contaminated soil three times a week over a four-year period, the exposure factor would be calculated as follows:

$$EF = \frac{(3 \text{ days/week}) \times (52 \text{ weeks/year}) \times (4 \text{ years})}{(4 \text{ years}) \times (365 \text{ days/year})}$$

$$EF = 0.43$$

In this example, the dose resulting from one day on which the child was exposed would be multiplied by 0.43 to yield the average daily dose over the four-year period.

In calculating the exposure factor, a judgement call is required in choosing the time period over which the exposure is averaged. The time period chosen depends on the expected health effects of the contaminant. In most cases, the expected health effects will be those such as cancer, or injury to organs that result from a continuous low level of exposure over a long period of time. In such cases, researchers generally average all exposures over a lifetime of 70 years.

In cases where children are exposed to contaminants, such as lead, that affect their development, a shorter period (4-12 years) can be chosen as the period over which exposure is averaged. When calculating the exposure factor for a child, the total exposure factor can be broken into three parts to allow changes in the child's body weight, and food, water and air consumption to be included in the final calculation. Researchers generally divide a child's life into three stages: the first six months, six months to 5 years, and 5 to 12 years old. To calculate a child's lifetime exposure, the exposure in each of these periods must be calculated separately. The separate exposures are then added together. The examples that follow show how this is done.

As a rule of thumb then, calculating the EDI requires averaging the exposure over a lifetime of 70 years, unless the contaminant can affect human development in a critical life stage such as childhood. Once again, if you are not sure, consult someone with a background in toxicology or epidemiology.

Estimating Exposures from Air Pollution

Air is an important pathway for contaminants and inhalation is the major route of exposure to contaminants that exist as atmospheric gases or are attached to airborne particles or fibres. In order to estimate an inhalation dose, an estimate of the amount of air a person breathes in a day is required. Standard values for the amount of air inhaled by various age groups are presented in TABLE 1. A person's sex, age, and the amount of physical activity are major factors affecting the volume of air breathed. Other factors influencing the volume of air breathed include: temperature, altitude, background air pollution, and a person's weight, height, whether or not they smoke, and whether they have suffered from heart disease.

To calculate the inhalation dose, it is assumed that 100% of the contaminant is absorbed after contact.

The amount of a contaminant absorbed into the body through inhalation (ED_a) can be estimated with the equation:

$$ED_a = \frac{C \times IR \times EF}{BW}$$

where:

ED_a = Estimated Dose through air inhalation: The air inhalation dose is expressed as milligrams of the contaminant inhaled per kilogram of body weight per day (mg/kg/day).

C = Concentration of the contaminant in the air, in milligrams per cubic metre of air (mg/m^3).

IR = Inhalation Rate: The amount of air a person breathes in a day, in cubic metres (m^3/day). Standard values are given in TABLE 1. If contaminated air is breathed for only part of a day, then inhalation rate is adjusted accordingly.

EF = Exposure Factor: Indicates how often the individual has been exposed to the contaminant over a lifetime (unitless). See previous discussion of exposure factors.

BW = Body Weight: The average body weight in kilograms (kg) based on an individual's age group. Standard values are given in TABLE 2.

EXAMPLE:

Estimate the exposure for an 11-year-old child (just prior to the 12th birthday) who has been exposed, for two hours per day every day since birth, to lead in outdoor air at a concentration of 8×10^{-6} mg/m³. Exposure ended at age 12 when the family moved to another area. Remember to calculate exposures for three age periods: 0 - < 0.5 years, 0.5 - < 5 years, and 5 - < 12 years. In this case the inhalation rate (IR) of contaminated air is a fraction of the total amount of air breathed in a day. It is calculated as follows:

$$\frac{\text{2 hours of exposure/day}}{\text{24 hours in a day}} \times \text{total daily amount of air inhaled}$$

The total daily amount of air inhaled changes as a child grows (see TABLE 1 for the values for each stage of a child's life). Multiplying each of these values by 2/24 (= 0.083) gives an IR of 0.166 m³/day, 0.415 m³/day, and 0.996 m³/day for each of the three age periods. The Exposure Factors for these periods are calculated as follows:

Age (yrs)	Exposure Factor
0 - < 0.5	183 days of exposure in first six months/4380 days in lifetime (12 years) = 0.042
0.5 - < 5	1642 days of exposure in second period/4380 days in lifetime (12 years) = 0.375
5 - < 12	2555 days of exposure in second period/4380 days in lifetime (12 years) = 0.583

Age (yrs)	Concentration	IR	EF	BW	Daily Inhalation Dose (mg/kg/day)
0 - < 0.5	8×10^{-3}	0.166	0.042	7	0.79×10^{-5}
0.5 - < 5	8×10^{-3}	0.415	0.375	13	9.58×10^{-5}
5 - < 12	8×10^{-3}	0.996	0.583	27	17.21×10^{-5}
ED_a					2.76×10^{-4}

The estimated daily dose of lead, which this child absorbs through the lungs, is estimated to be 2.76×10^{-4} mg/kg/day.

Modified from ATSDR, 1992.

Note: This example consists of fictitious data.

Estimating Water Ingestion Exposures

Drinking contaminated water can lead to significant exposures of hazardous substances. In order to estimate the exposure to contaminants from drinking water, the amount of water people drink must be determined. Ingestion of water includes straight water, water in coffee, tea or other drinks made with tap water, and water in cooked food. If precise values for your community are not available, the standard values for the daily ingestion of water, which are presented in TABLE 1, can be used.

To calculate the water ingestion dose, it is assumed that 100% of the contamiant is absorbed after ingestion.

The amount of a contaminant absorbed into the body through drinking water (ED_w) can be estimated with the following equation:

$$ED_w = \frac{C \times IR \times EF}{BW}$$

where:

ED_w = Estimated Dose from drinking water: The water ingestion dose is expressed as milligrams of the contaminant ingested, per kilogram of body weight per day (mg/kg/day).

C = Concentration of the contaminant in the water, in milligrams per litre of water (mg/L).

IR = Ingestion Rate: The amount of water a person drinks in a day, in litres (L/day). Standard values are given in TABLE 1. If the person drinks from the contaminated water source for only a part of the day (for example, only at work), then the ingestion rate is adjusted accordingly.

EF = Exposure Factor: Indicates how often the individual has been exposed to the contaminant over a lifetime. See previous discussion of exposure factors (unitless).

BW = Body Weight: The average body weight in kilograms (kg) based on an individual's age group. Standard values are given in TABLE 2.

EXAMPLE:

Calculate human exposure to contaminants in the drinking water at work. The water is contaminated with 367 mg/L methylchloride. To calculate an adult exposure dose over a lifetime, assume a body weight of 70 kg (TABLE 2) and a 30-year career, with 5 working days per week, and 50 work weeks per year. Assume a water ingestion rate (IR) of 1.5 L/day (TABLE 1).

$$EF = \frac{30 \text{ work years} \times 50 \text{ work weeks/year} \times 5 \text{ work days/week}}{70 \text{ years/lifetime} \times 365 \text{ days/year}}$$

$$= 0.29$$

Then, $$ED_w = \frac{C \times IR \times EF}{BW}$$

$$= \frac{367 \text{ mg/L} \times 1.5 \text{ L/day} \times 0.29}{70 \text{ kg}}$$

$$= 2.28 \text{ mg/kg/day}$$

Assuming that the workplace is the only source of exposure, the lifetime exposure to methylchloride of the adult in the above conditions is calculated to be 2.28 mg/kg/day.

Modified from ATSDR, 1992

Note: This example consists of fictitious data.

Estimating Soil Ingestion Exposures

Soil can be eaten unintentionally, when soil sticks to hands or to food. Soil can also be ingested when other objects are put in the mouth or swallowed. All children do this to some extent. How often children swallow and mouth objects varies. Children between the ages of one and three years, and children with neurologic disorders develop a "swallowing object habit" (known as pica) more often than other children.

Standard values for the daily ingestion of soil by children who do not swallow objects regularly, and adults are presented in TABLE 1. To calculate the soil ingestion dose, it is assumed that 100% of the contaminant ingested with soil is absorbed.

The amount of a contaminant absorbed into the body by eating soil (ED_s) can be estimated with the equation:

$$ED_s = \frac{C \times IR \times EF \times 10^{-6}}{BW}$$

where:

ED_s = Estimated Dose through eating soil: The soil ingestion dose is expressed as milligrams of the contaminant eaten, per kilogram of body weight per day (mg/kg/day).

C = Concentration of the contaminant in the soil in milligrams per kilogram of soil (mg/kg).

IR = Ingestion Rate: The amount of soil a person eats in a day, in milligrams (mg/day). Standard values are given in TABLE 1. If the individual can only eat contaminated soil for part of the day (for example, a child exposed to contaminated soil at a daycare centre attended only in the morning), then the ingestion rate can be adjusted accordingly.

EF = Exposure Factor: Indicates how often the individual has been exposed to the contaminant over a lifetime. See previous discussion of exposure factors (unitless).

BW = Body Weight: The average body weight in kilograms (kg) based on an individual's age group. Standard values are given in TABLE 2.

NOTE: The equation includes a conversion factor of 10^{-6}, which is required to convert the concentration of the contaminant in the soil (C) from mg/kg of soil to mg/mg of soil. In this way, the units for soil concentration are the same as those for soil ingestion (both now in milligrams of soil).

EXAMPLE:

Calculate the exposure of an adult to soil at the workplace. The soil is contaminated with 0.9 mg/kg of cadmium. To calculate an adult exposure dose over a lifetime, assume a body weight of 70 kg (TABLE 2) and a 30-year career, with 5 working days per week, and 50 work weeks per year. Assume a soil ingestion rate (IR) of 20 mg/day (TABLE 1).

$$EF = \frac{\text{30 work years x 5 work days/week x 50 work weeks/year}}{\text{70 years/lifetime x 365 days/year}}$$

$$= 0.29$$

Then, $$ED_s = \frac{C \times IR \times EF \times 10^{-6}}{BW}$$

$$= \frac{0.9\ mg/kg \times 20\ mg/day \times 0.29 \times 10^{-6}}{70\ kg}$$

$$= 7.46 \times 10^{-6}\ mg/kg/day\ cadmium$$

Assuming that the workplace is the only source of exposure, the exposure to cadmium of the adult in the above conditions is calculated to be 7.46×10^{-6} mg/kg/day, averaged over a lifetime.

Modified from ATSDR, 1992

Note: This example consists of fictitious data.

Estimating Food Ingestion Exposures

How much of a contaminant is eaten with food requires a knowledge of eating habits of the group or population being studied, and the concentration of the contaminant in different kinds of food. Eating habits - the amount of each different kind of food eaten - in your community may differ from the national average. For example, in some communities, far more fish is eaten than the average for all Canadians. Groups within the community may also vary from national averages. In general, older people eat more fish, as do sport fishermen. When values for local eating habits are available, they should be used to calculate the exposure dose. The average amount of various food groups eaten by Canadians are shown in TABLE 3, and can be used when local values are not available.

The amount of a contaminant taken into the body with food (ED_f) requires a separate calculation for each kind of food (or food group) that is eaten. That makes the equation look more complicated, but the extra steps are just a repetition of the basic equation used in calculating all other estimated doses (ED). The total estimated dose from food can be calculated with the following equation:

$$ED_f = \frac{\text{(food group 1)}}{CF \times CR \times EF} + \frac{\text{(food group 2)}}{CF \times CR \times EF} + \ldots + \frac{\text{(last food group)}}{CF \times CR \times EF}$$
$$BW \qquad BW \qquad BW$$

where:

ED_f = Estimated Dose from food: The food ingestion dose is expressed as milligrams of the contaminant eaten per kilogram of body weight per day (mg/kg/day).

CF = Concentration in food groups: The concentration of the contaminant in the food group is expressed in milligrams of contaminant per gram of food (mg/g).

CR = Consumption Rate: The amount of food from that food group eaten, expressed in milligrams per day (mg/day). Standard values are given in TABLE 3.

EF = Exposure Factor: Indicates how often the individual has eaten the contaminated food in a lifetime (unitless). See previous discussion of exposure factors.

BW = Body Weight: The average body weight in kilograms (kg) based on an individual's age group. Standard values are given in TABLE 2.

NOTE: It is assumed that 100% of the contaminant eaten with the food is absorbed into the body.

The calculation of the food ingestion dose of a contaminant in home-grown foods is similar, but takes into account the percentage of contaminated food that is home-grown:

$$ED_f = \frac{\text{(food group 1)}}{CF \times CR \times EF \times PH} + \frac{\text{(food group 2)}}{CF \times CR \times EF \times PH} + \ldots + \frac{\text{(last food group)}}{CF \times CR \times EF \times PH}$$
$$BW \qquad BW \qquad BW$$

where,

PH = percentage of that food group that is home-grown

Agricultural lands: assume that 50% of the meat, milk, fruit and vegetables eaten by residents in agricultural areas are grown on the farm.

Residential lands: assume that 7% of the fruit and vegetables are grown in the backyard garden. No meat or milk is produced at home.

EXAMPLE:

Estimate the exposure of a child, between the ages of 5 and 11 years, to lead from food that is produced on the farm where she lives. Since she lives on a farm (i.e., agricultural land), assume that 50% (i.e., PH = 0.5) of the meat, milk, and fruit and vegetables eaten by this child are produced on the farm. To calculate exposure dose through food, assume a body weight of 27 kg (TABLE 2) and a consumption rate (CR) of meat, dairy products, fruit and vegetables to be 120 g/day, 609 g/day and 198 g/day respectively (TABLE 3). Assume an exposure factor (EF) of 1.0 since the child eats every day. This estimate is only for lead from the locally grown food. It does not consider other sources of lead such as from purchased food.

Food Group	CF	CR	PH	EF	BW	Daily Intake of Contaminant (mg/kg/day)
Meat	0.01	120	0.5	1.0	27	0.022
Dairy Products	0.005	609	0.5	1.0	27	0.056
Vegetables	0.002	198	0.5	1.0	27	0.007
ED_f						0.085

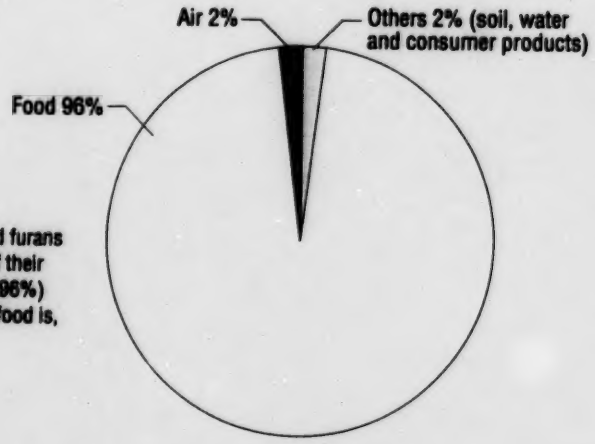
The daily intake of lead from home-grown food, by this child between the ages of 5 and 11 years, is estimated to be 0.085 mg/kg/day.

Modified from ATSDR, 1992.

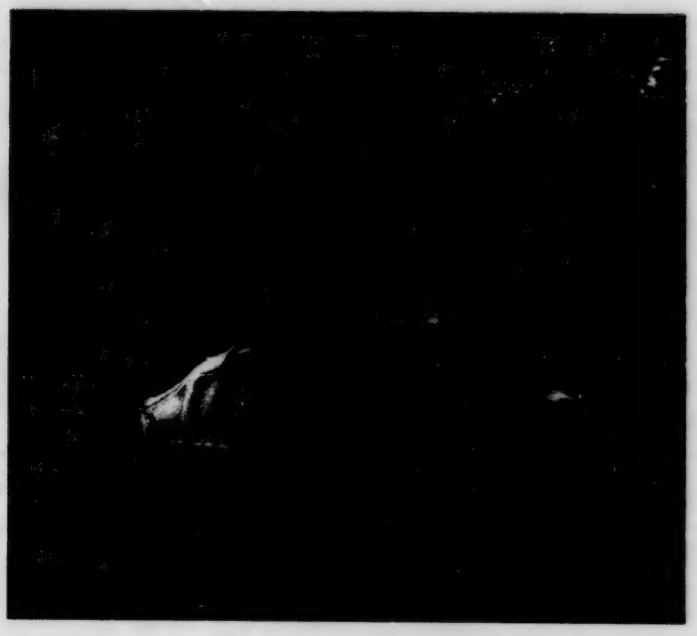
Note: This example consists of fictitious data.

FIGURE 3:

Food Ingestion as the Major Exposure Route for Dioxins and Furans in Canadians



While few people are exposed to dioxins and furans at levels considered a risk to health, most of their exposure is from some contaminated food (96%) rather than from air or other sources. Most food is, in fact, free of dioxins and furans.



Estimating Skin Exposure Doses (Water and Soil)

The absorption of contaminants through the skin depends on a number of factors, including:

- the total surface area of the exposed skin;
- what part of the body was in contact with the contaminant;
- length of contact;
- concentration of the chemical on the skin;
- the ability of the specific contaminant to move through the skin into the body. This is called the "chemical-specific permeability";
- the type of substance through which the contaminant comes into contact with the skin. For example, is the contaminant dissolved in water, or in soil, when it comes into contact with the person? and
- whether the skin is damaged in any way before coming into contact with the contaminant.

The area of the skin that is exposed will be influenced by the activity being performed and the season of the year. Total skin surface area also varies with age. TABLE 2 provides values for skin surface area of different parts of the body for adults and for children.

Skin Exposure Dose from Contaminated Water

The absorption of contaminants in water through the skin occurs during bathing, showering or swimming. Worker exposure via this route depends on the type of work performed, protective clothing worn, and the extent and length of water contact. How quickly a chemical travels through the skin is affected by the physical and chemical properties of the substance, including:

- the weight, size and shape of the molecules of the chemical;
- its electrostatic charge; and
- whether or not it can be dissolved in water, and in fats.

In general, chemicals that travel quickly through the skin have low molecular weights, no electrostatic charge, and can be dissolved in fat. How fast a chemical travels can be measured and expressed as a value, called the permeability constant. This constant is different for every

chemical. Absorption through the skin can go more quickly where skin cuts and abrasions, or skin conditions such as psoriasis or eczema, are present.

To estimate the absorption of a contaminant in water through the skin, a permeability constant (P) should be used. However, such constants have been established for only a few chemicals. Even for chemicals that have been tested, the value of the constant can depend to a very large degree on the design of the experiment used to test the chemical. Skin permeability constants for some contaminants in water are shown in TABLE 4. To be on the safe side and not underestimate the exposure, a permeability of 1.0 cm/hour can be used in the calculations. This is done by a number of government agencies, rather than using the constants such as those in TABLE 4.

The amount of a contaminant in water absorbed into the body through skin contact (ED_{ws}) can be estimated with the equation:

$$ED_{ws} = \frac{C \times P \times SA \times ET \times EF \times 10^{-3}}{BW \times AT}$$

where:

ED_{ws} = Estimated Dose through water on the skin: The skin exposure dose is expressed as milligrams absorbed through the skin per kilogram of body weight per day (mg/kg/day).

C = Concentration of the contaminant in the water in milligrams per litre of water (mg/L).

P = Permeability Constant: expressed as the number of centimetres the chemical will travel through the skin in an hour (cm/h). A cautious approach assumes a constant of 1.0 cm/h rather than the constants shown in TABLE 4. See previous discussion.

SA = Surface Area: The surface area is the skin that is exposed to the contaminated water, expressed in square centimetres (cm^2). TABLE 2 contains the average surface areas for various parts of the body.

ET = Exposure Time: The number of hours per day that the contaminated water is in contact with the skin.

EF = Exposure factor: Indicates how often the individual has been exposed to the contaminated water over a lifetime (unitless).

BW = Body Weight: The average body weight in kilograms (kg) based on an individual's age group. Standard values are given in TABLE 2.

NOTE: The factor of 10^{-3} is required to convert the volume units of water from litres (L) to cubic centimetres (cm^3) (1L = 1,000 cm^3). This conversion is necessary, so that the contaminant concentration (C) uses the same units as the permeability constant (P) and the surface area (SA).

EXAMPLE:

Calculate the exposure through the skin of a contaminant in the water for a woman who lives in an area where the benzene concentration (C) has been found to be 0.002 mg/L. She has been living in her house for 25 years and has bathed every day. Ignore other skin contact with the water. Assume that the whole body (SA = 18,200 cm^2) is exposed for a quarter of an hour (ET = 0.25) during bathing. Benzene moves through the skin at a rate of 0.11 cm/h (P). Calculate the daily skin exposure of this woman, averaged over her lifetime which is assumed to be 70 years.

$$EF = \frac{25 \text{ years} \times 365 \text{ days/year}}{70 \text{ years} \times 365 \text{ days/year}}$$

$$= 0.36$$

Then,

$$ED_{ev} = \frac{C \times P \times SA \times ET \times EF \times 10^{-3}}{BW}$$

$$ED_{ev} = \frac{0.002 \text{ mg/L} \times 0.11 \text{ cm/hour} \times 18{,}200 \text{ cm}^2 \times 0.25 \text{ hours/day} \times 0.36 \times 10^{-3}}{70 \text{ kg}}$$

$$= 5.1 \times 10^{-6} \text{ mg/kg/day}$$

The skin exposure of this woman to benzene from bathing water, averaged over her lifetime, is 5.1×10^{-6} mg/kg/day.

Modified from ATSDR, 1992.

Note: This example consists of fictitious data.

Skin Exposure Dose through Contaminated Soil

The absorption of contaminants from soil or dust through the skin depends on a number of factors:

- the area of contact;
- the duration of contact;
- the chemical and physical attraction between the contaminant and the soil;
- the ability of the contaminant to penetrate the skin;
- the weight of individual molecules of the particular contaminant; and
- how well the contaminant dissolves in water and fats.

Often, not all of the contaminant in the soil is available to the skin for absorption. Many organic chemicals are firmly attached to organic matter in soil so that they can move through the skin only with difficulty. In addition, only the contaminant molecules that are in direct contact with the skin can be absorbed. The amount of a contaminant that can be absorbed from the soil can be tested. The results of such an experiment gives a "bioavailability factor" specific to the contaminant, such as those shown in TABLE 5. These bioavailability factors may also vary according to the experimental method used to determine them. The most cautious approach is to use a bioavailability factor of 1.0 (= 100% absorption) in the calculations.

Another variable factor in calculating absorption through the skin is how well the soil sticks to the skin. Data on dust and soil adherence to the skin are limited. Standard values for the total soil adhered (A) to the skin for various age groups are presented in TABLE 1.

The amount of a contaminant that is absorbed through skin contact with contaminated soil (ED_{ss}) can be estimated using the following equation:

$$ED_{ss} = \frac{C \times A \times BF \times EF \times 10^{-6}}{BW}$$

where:

ED_{ss} = Estimated Dose through skin contact with soil: This dose is expressed as milligrams of the contaminant absorbed through the skin per kilogram of body weight per day (mg/kg/day).

C = Concentration of the contaminant in the soil, in milligrams per kilogram of soil (mg/kg).

A = Total soil Adhered: The amount of soil that will stick to a person, expressed in milligrams per day (mg/day). Standard values that can be used here are found in TABLE 1.

BF = Bioavailability Factor: The percentage of the contaminant in the soil that is actually free to move out of the soil and through the skin (unitless). A cautious approach is to use a factor of 1.0 (= 100% availability) instead of the factors shown in TABLE 5. See previous discussion.

EF = Exposure Factor: Indicates how often the individual has been exposed to the contaminant over a lifetime (unitless). See previous discussion of exposure factors.

BW = Body Weight: The average body weight in kilograms (kg) based on an individual's age group. Standard values are given in TABLE 2.

NOTE: The equation includes a conversion factor of 10^{-6}, which is required to convert the concentration of the contaminant in the soil (C) from mg/kg of soil to mg/mg of soil. In this way, the units for soil concentration are the same as those for total soil adhered to the skin (both now in milligrams of soil).

EXAMPLE:

Estimate the exposure for an 11-year-old child (just prior to the 12th birthday) who has had skin contact with a contaminated soil every day since birth. The concentration of the contaminant in the soil (C) is 100 mg/kg. Assume that the bioavailability factor (BF) is 1.0 (= 100% availability). Remember to calculate exposures for three age periods: 0 - < 0.5 years, 0.5 - < 5 years, and 5 - < 12 years. In this case the total soil adhered (A) to the child is 2200 mg/day, 3500 mg/day, and 5800 mg/day respectively for each of the three age periods (see TABLE 1). The exposure factors for each age period are calculated as follows:

Age (yrs)	Exposure Factor		
0 - < 0.5	183 days of exposure in the first period/4380 days in lifetime	=	0.042
0.5 - < 5	1642 days of exposure in the second period/4380 days in lifetime	=	0.375
5 - < 12	2555 days of exposure in the third period/4380 days in lifetime	=	0.583

Age (yrs)	C	A	BF	EF	Conversion Factor	BW	Daily Skin Exposure (mg/kg/day)
0 - < 0.5	100	2200	1.0	0.042	10^{-6}	7	0.001
0.5 - < 5	100	3500	1.0	0.375	10^{-6}	13	0.010
5 - < 12	100	5800	1.0	0.583	10^{-6}	27	0.013
ED_{ss}							0.024

The daily intake of contaminant by this child is estimated to be 0.024 mg/kg/day, averaged over a lifetime of 12 years.

Modified from ATSDR, 1992.

Note: This example consists of fictitious data.

Calculating the Estimated Daily Intake (EDI)

Once you have calculated each of the separate Estimated Doses, you can add them all together to get the total Estimated Daily Intake (EDI) for the contaminant. The following example shows how it is done.

Estimated Daily Intake (EDI) = $ED_a + ED_w + ED_s + ED_f + ED_{ws} + ED_{ss}$

where, ED_a is the estimated inhalation dose,

ED_w is the estimated water ingestion dose,

ED_s is the estimated soil ingestion dose,

ED_f is the estimated food ingestion dose,

ED_{ws} is the estimated water skin exposure dose,

ED_{ss} is the estimated soil skin exposure dose.

EXAMPLE:

Calculate the EDI of pentachlorophenol of a person living near a suspected contaminated site. Assume you are averaging exposure over a lifetime of 70 years. The Estimated Dose for each possible combination of exposure pathway and exposure route are given below. Note that each Estimated Dose has been calculated separately for each of the five life stages. This can increase the accuracy of the total estimate. Each Estimated Dose was calculated using the equations described on the preceding pages. All values are expressed in nanograms of pentachlorophenol per kilogram of body weight per day (ng/kg/day).

	AGE (years)					
PATHWAY	**0 - < 0.5**	**0.5 - < 5**	**5 - < 12**	**12 - < 20**	**20+**	**Daily Exposure (ng/kg/day)**
Air Inhalation	0.079	0.823	1.430	1.634	6.786	$ED_a = 10.752$
Water Ingestion	0.001	0.007	0.005	0.006	0.029	$ED_w = 0.048$
Soil Ingestion	0.007	0.012	0.014	0.016	0.064	$ED_s = 0.113$
Food Ingestion	0.705	6.771	4.990	5.703	19.786	$ED_f = 37.955$
Water Skin Exposure	0.003	0.003	0.002	0.002	0.014	$ED_{ws} = 0.024$
Soil Skin Exposure	0.004	0.071	0.009	0.010	0.036	$ED_{ss} = 0.013$
	0.799	7.687	6.450	7.371	26.715	EDI = 49.022

The daily intake of pentachlorophenol by this person is estimated to be 49.022 ng/kg/day (equivalent to 0.049 µg/kg/day), averaged over a lifetime of 70 years.

Note: This example consists of fictitious data.

Comparing EDI to TDI or RsD

To determine whether or not the Estimated Daily Intake (EDI) you have calculated is at a level associated with increased risk to health, compare it to the Tolerable Daily Intake (TDI) or the Risk-specific Dose (RsD), whichever is appropriate for that contaminant.

Non-carcinogen

EXAMPLE:

Consider the exposure of a commercial fisherman to methyl mercury, whose EDI has been estimated at 0.61 µg/kg/day. How does this compare with the known TDI?

The TDI for methyl mercury from TABLE 6 is 0.47 µg/kg/day. The EDI of 0.61 µg/kg/day is about 1.3 times above the TDI. This indicates that the exposure exceeds the level considered a risk to health. Steps should be taken to reduce exposure to methyl mercury in this situation.

Carcinogen

EXAMPLE:

The EDI for pentachlorophenol, calculated in the example on the previous page, is found to be 49.022 ng/kg/day (=4.9×10^{-5} mg/kg/day). Assume a slope factor (SF) of 0.12 $(mg/kg/day)^{-1}$ for pentachlorophenol and that the level of risk for cancer that was considered acceptable was one excess cancer death per 100,000 people exposed (i.e., 1×10^{-5}). How does the EDI compare with the RsD?

1. Calculate the RsD for pentachlorophenol.

$$RsD = \frac{R}{SF}$$

$$= \frac{1 \times 10^{-5}}{0.12\ (mg/kg/day)^{-1}}$$

$$= 8.3 \times 10^{-5}\ mg/kg/day$$

2. Compare EDI to RsD

The EDI for pentachlorophenol exposure is 4.9×10^{-5} mg/kg/day which is about one-half the RsD calculated at 8.3×10^{-5} mg/kg/day. This indicates that the exposure is within the level of risk of cancer considered acceptable.

Note: These examples consist of fictitious data.

Another Way to Support Your Results

Guidelines have been prepared for many chemical contaminants found in soil and water. If contaminated levels in soil or water exceed the guidelines, then further investigation of the contamination is recommended. The guidelines, called Interim Assessment Criteria for Soil and Water, were prepared by the Canadian Council of Ministers of the Environment (CCME), and are shown in TABLE 8. If the contaminant concentrations in the soil or water of your community exceed these levels, you can use them to support your request for more detailed study of the problem.

7. ESTIMATED DOSE FOR IONIZING RADIATION: EQUATIONS AND EXAMPLES

Exposure to sources of ionizing radiation outside the body will result in direct external exposure. Inhaling air, or ingesting food, water, or soil, which contains natural or human-made radionuclides can lead to an internal radiation exposure which may be received over an extended period following inhalation or ingestion. As with chemical contaminants, the amount of air, food, water, and soil taken into the body must be determined in order to estimate the dose received from one year of inhalation or ingestion.

Standard values for daily inhalation and ingestion rates are the same as presented in TABLE 1 and TABLE 3. Dose conversion factors (DCF) for children and adults can be obtained from publications issued by the International Commission on Radiological Protection, the National Radiation Protection Board (U.K.), or by contacting the Radiation Protection Bureau, Health Canada, which can provide expertise in this area. DCFs for selected radionuclides are presented in TABLE 7.

Exposure Factors

For radionuclides, the averaging period over which exposure is estimated is taken to be one year (365 days), since exposure limits are expressed on an annual basis. For example, if a worker is exposed four times a week over a work year of 50 weeks, the exposure factor would be calculated as follows:

$$EF = \frac{(50 \text{ work weeks/year}) \times (4 \text{ work days/week})}{(365 \text{ days/year})}$$

$$EF = 0.55$$

Estimating Air Inhalation Radiation Exposures

The committed dose from internal radiation exposure as a result of air inhalation (ED_a) can be estimated with the equation:

$$ED_a = C \times IR \times CF \times EF \times DCF$$

where:

ED_a = Estimated Dose over 50 years (for adults) or 70 years (children) through air inhalation in one year: The air inhalation dose is expressed as sieverts (*Sv*) or millisieverts (*mSv*).

C = Radionuclide activity concentration in air, in becquerels per cubic metre of air (*Bq*/m³).

IR = Inhalation Rate: The amount of air a person breathes in a day, in cubic metres (m³/day). Standard values are given in TABLE 1. If contaminated air is breathed for only part of a day, then inhalation rate is adjusted accordingly.

CF = Conversion Factor: The factor of 365 days is required to convert the Inhalation Rate (IR) from units/day to units/year.

EF = Exposure Factor: Indicates how often the individual has been exposed to the contaminant over the year (unitless).

DCF = Dose Conversion Factor (specific for each radionuclide): The extended 50-year or 70-year dose resulting from the inhalation of 1 *Bq* of a given radionuclide (*Sv*/*Bq*). Selected DCFs are presented in TABLE 7.

EXAMPLE:

Estimate the committed dose of radiation for an adult male from one year of inhalation of tritium in air at the workplace. Assume a 50-week work year, a 5-day work week with an 8-hour work day. Air inhalation rate is assumed to be 23 m³ over 24 hours (see TABLE 1) so that the air inhalation rate (IR) attributable to 8 hours at the workplace is 7.67 m³. The tritium activity concentration (C) in the air at the workplace was measured at 0.1 *Bq*/m³ and the DCF for tritium via inhalation is 1.80×10^{-11} *Sv*/*Bq* (see TABLE 7).

$$EF = \frac{1 \text{ work year} \times 50 \text{ work weeks/year} \times 5 \text{ work days/week}}{365 \text{ days/year}}$$

$$= 0.68$$

Then,

$$ED_a = C \times IR \times CF \times EF \times DCF$$

$$= 0.1 \text{ Bq/m}^3 \times 7.67 \text{ m}^3\text{/day} \times 365 \text{ days} \times 0.68 \times 1.8 \times 10^{-11} \text{ Sv/Bq}$$

$$= 3.4 \times 10^{-6} \text{ Sv}$$

$$= 3.4 \times 10^{-3} \text{ mSv}$$

The estimated 50-year committed dose from tritium, as a result of one year of inhalation at the workplace, is 3.4×10^{-3} *mSv*.

Note: This example consists of fictitious data.

Estimating Water Ingestion Radiation Exposures

The committed dose from internal radiation exposure as a result of water ingestion (ED_w) can be estimated with the equation:

$$ED_w = C \times IR \times CF \times EF \times DCF$$

where:

ED_w = Estimated Dose over 50 years (for adults) or 70 years (children) through water ingestion in one year: The water ingestion dose is expressed as sieverts (*Sv*) or millisieverts (*mSv*).

C = Radionuclide activity concentration in drinking water, in becquerels per litre of water (*Bq*/L).

IR = Ingestion Rate: The amount of water a person drinks in a day, in litres (L/day). Standard values are given in TABLE 1. If the person drinks from the contaminated water source for only a part of the day (for example, only at work), then the ingestion rate is adjusted accordingly.

CF = Conversion Factor: The factor of 365 days is required to convert the Ingestion Rate (IR) from units/day to units/year.

EF = Exposure Factor: Indicates how often the individual has been exposed to the contaminant over the year (unitless).

DCF = Dose Conversion Factor (specific for each radionuclide): The extended 50-year or 70-year dose resulting from the ingestion of 1 *Bq* of a given radionuclide (*Sv*/*Bq*). Selected DCFs are presented in TABLE 7.

EXAMPLE:

Estimate the committed dose of radiation for an adult male from one year of ingestion of strontium-90 in water at the workplace. Assume a 50-week work year and a 5-day work week. The total daily water ingestion rate is assumed to be 1.5 L/day (see TABLE 1) with one-half (IR = 0.75 L/day) being consumed at the workplace. The strontium-90 activity concentration (C) in the water at the workplace was measured at 5.0×10^{-3} *Bq*/L and the DCF for strontium-90 via ingestion is 2.80×10^{-8} *Sv*/*Bq* (see TABLE 7).

$$EF = \frac{1 \text{ work year} \times 50 \text{ work weeks/year} \times 5 \text{ work days/week}}{365 \text{ days/year}}$$

$$= 0.68$$

Then, $ED_w = C \times IR \times CF \times EF \times DCF$

$= 5.0 \times 10^{-3}$ *Bq*/L $\times$ 0.75 L/day $\times$ 365 days $\times$ 0.68 $\times$ 2.8×10^{-8} *Sv*/*Bq*

$= 2.6 \times 10^{-5}$ *Sv*

$= 2.6 \times 10^{-5}$ *mSv*

The estimated 50-year committed dose from strontium-90, as a result of one year of water ingestion at the workplace, is 2.6×10^{-5} *mSv*.

Note: This example consists of fictitious data.

Estimating Soil Ingestion Radiation Exposures

The committed dose from internal radiation exposure as a result of soil ingestion (ED_s) can be estimated with the equation:

$$ED_s = C \times IR \times CF \times EF \times DCF$$

where:

ED_s = Estimated Dose over 50 years (for adults) or 70 years (children) through soil ingestion in one year: The soil ingestion dose is expressed as sieverts (*Sv*) or millisieverts (*mSv*).

C = Radionuclide activity concentration in soil, in becquerels per kilogram of soil (*Bq*/kg).

IR = Ingestion Rate: The amount of soil a person eats in a day, in milligrams (mg/day). Standard values are given in TABLE 1. If the person ingests contaminated soil for only a part of the day (for example, only at work), then the ingestion rate is adjusted accordingly.

CF = Conversion Factor: The factor of 365 days is required to convert the Ingestion Rate (IR) from units/day to units/year.

EF = Exposure Factor: Indicates how often the individual has been exposed to the contaminant over the year (unitless).

DCF = Dose Conversion Factor (specific for each radionuclide): The extended 50-year or 70-year dose resulting from the ingestion of 1 *Bq* of a given radionuclide (*Sv*/*Bq*). Selected DCFs are presented in TABLE 7.

EXAMPLE:

Estimate the committed dose of radiation for an adult male from one year of accidental ingestion of cesium-137 in soil at the workplace. Assume a 50-week work year, a 5-day work week with an 8-hour work day. The soil ingestion rate is assumed to be 20 mg over 24 hours (see TABLE 1) so that the soil ingestion rate (IR) attributable to 8 hours at the workplace is 6.67 mg. The cesium-137 activity concentration (C) in the soil at the workplace was measured at 10.0 *Bq*/kg, which is equivalent to 1×10^{-5} *Bq*/mg. The DCF for cesium-137 via ingestion is 1.30×10^{-8} *Sv*/*Bq* (see TABLE 7).

$$EF = \frac{1 \text{ work year} \times 50 \text{ work weeks/year} \times 5 \text{ work days/week}}{365 \text{ days/year}}$$

$$= 0.68$$

Then, $ED_s = C \times IR \times CF \times EF \times DCF$

$= 1 \times 10^{-5}$ *Bq*/mg $\times$ 6.67 mg/day $\times$ 365 days $\times$ 0.68 $\times$ 1.3×10^{-8} *Sv*/*Bq*

$= 2.2 \times 10^{-10}$ *Sv*

$= 2.2 \times 10^{-7}$ *mSv*

The estimated 50-year committed dose from cesium-137, as a result of one year of accidental soil ingestion at the workplace, is 2.2×10^{-7} *mSv*.

Note: This example consists of fictitious data.

Estimating Food Ingestion Radiation Exposures

The committed dose from internal radiation exposure due to food consumption (ED_f) requires a separate calculation for each kind of food (or food group) that is eaten. The extra steps are just a repetition of the basic equation used in calculating all other estimated doses. The total estimated dose from food can be calculated with the following equation:

$$ED_f = (C \times CR \times CF \times EF \times DCF)_{\text{food group 1}} + (C \times CR \times CF \times EF \times DCF)_{\text{food group 2}} + \ldots + (C \times CR \times CF \times EF \times DCF)_{\text{last food group}}$$

where:

ED_f = Estimated Dose over 50 years (adults) or 70 years (children) from food ingestion in one year: The food ingestion dose is expressed as sieverts (*Sv*) or millisieverts (*mSv*).

C = Radionuclide activity concentration in the food group, in becquerels per kilogram (*Bq*/kg) or per gram (*Bq*/g) of food.

CR = Consumption Rate: The amount of food from that food group eaten, expressed in grams per day (g/day). Standard values are given in TABLE 3.

CF = Conversion Factor: The factor of 365 days is required to convert the Consumption Rate (CR) from units/day to units/year.

EF = Exposure Factor: Indicates how often the individual has been exposed to the contaminant over the year (unitless).

DCF = Dose Conversion Factor (specific for each radionuclide): The extended 50-year or 70-year dose resulting from the ingestion of 1 *Bq* of a given radionuclide (*Sv*/*Bq*). Selected DCFs are presented in TABLE 7.

EXAMPLE:

Estimate the committed dose of radiation for an adult male from one year of ingestion of cesium-137 and radium-226 in food at the workplace. Assume a 50-week work year, and a 5-day work week with one meal eaten from food prepared at the workplace so that approximately one third of the average amount of food eaten, presented in TABLE 3, is consumed in the workplace. The radionuclide activity concentrations (C) is measured in three food groups and their DCFs via ingestion (see TABLE 7) are presented below.

$$EF = \frac{1 \text{ work year} \times 50 \text{ work weeks/year} \times 5 \text{ work days/week}}{365 \text{ days/year}}$$

$$= 0.68$$

Food Group	Radionuclide	C	CR	CF	EF	DCF	ED_f for each food group (*Sv*)
Meat	cesium-137	2×10^{-2} *Bq*/g	61	365	0.68	1.3×10^{-8}	3.9×10^{-6}
Dairy Products	cesium-137	5×10^{-5} *Bq*/g	94	365	0.68	1.3×10^{-8}	1.5×10^{-8}
Vegetables	radium-226	2×10^{-3} *Bq*/g	83	365	0.68	2.2×10^{-7}	9.1×10^{-6}
ED_f							1.3×10^{-5}

The estimated 50-year committed dose from cesium-137 and radium-226, as a result of food consumption at the workplace over one year, is 1.3×10^{-5} *Sv* (1.3×10^{-2} *mSv*).

Note: This example consists of fictitious data.

Calculating the Estimated Dose (ED) for Ionizing Radiation

Once you have estimated the committed doses for each pathway and radionuclide resulting in internal radiation exposure, you can add them all together to get the total Estimated Dose for all radionuclides taken into the body in one year ($ED_{internal}$). This value is then added to the Estimated Dose measured from external sources ($ED_{external}$) to obtain the total Estimated Dose (ED) for ionizing radiation. The following example shows how it is done.

Estimated Dose (ED) = $ED_{external} + ED_{internal}$

= $ED_{external} + ED_a + ED_w + ED_s + ED_f$

where,

$ED_{external}$ is the estimated dose from external radiation received during the year,
ED_a is the estimated committed dose from radionuclides inhaled through the air during the year,
ED_w is the estimated committed dose from radionuclides taken in by drinking water during the year,
ED_s is the estimated committed dose from radionuclides taken in by eating soil during the year,
ED_f is the estimated committed dose from radionuclides taken in by eating food during the year.

EXAMPLE:

Estimate the ED for exposure to ionizing radiation from artificial sources for an adult male in the workplace. Assume a 50-week work year, and a 5-day work week and an 8-hour work day with one meal eaten from food prepared and consumed at the workplace. The ED for internal exposure via each possible pathway have been calculated in the four previous examples (air: 3.4×10^{-6} *mSv*; water: 2.6×10^{-5} *mSv*; soil: 2.2×10^{-7} *mSv*; food: 1.3×10^{-2} *mSv*). The $ED_{external}$ for radiation exposure from artificial sources has been measured by instruments and estimated to be 2.0×10^{-2} *mSv* above the natural background radiation.

ED = $ED_{external} + ED_a + ED_w + ED_s + ED_f$

= $2.0 \times 10^{-2} + 3.4 \times 10^{-6} + 2.6 \times 10^{-5} + 2.2 \times 10^{-7} + 1.3 \times 10^{-2}$

= 3.3×10^{-2} *mSv*

The Estimated Dose from both internal and external radiation exposure to ionizing radiation during one year at the workplace is estimated to be 3.3×10^{-2} *mSv*.

Note: This example consists of fictitious data.

Comparing ED with Radiation Exposure Limits

To determine whether or not the Estimated Dose (ED) from all artificial sources you have calculated is at a level associated with increased risk to health, compare it to the radiation exposure limit of 1 *mSv* issued by the International Commission on Radiological Protection (ICRP). In addition, compare the estimated annual dose you have calculated for the drinking water pathway (ED_w) to the drinking water guideline of 0.1 *mSv* issued by Health Canada. The drinking water guideline applies to the total dose from all radionuclides in drinking water, both natural and artificial in origin.

EXAMPLE:

Consider the workplace exposure to ionizing radiation of the man described in the previous examples, whose total ED (external + internal) is estimated at 3.3×10^{-2} *mSv* and whose internal exposure from drinking water (ED_w) is 2.6×10^{-5} *mSv*. How do these compare with the ICRP and Health Canada limits?

The ICRP public dose limit applies to the total dose to an individual from all sources during the year, excluding the natural background radiation and exposures for medical purposes. The workplace exposure of 3.3×10^{-2} *mSv*, described in the above example, is well below the public dose limit of 1 *mSv* received or committed in one year.

In the case of drinking water, assuming that the total dose received from the water supply is from strontium-90, as given in the previous example, the ED_w of 2.6×10^{-5} *mSv* is well below the Health Canada guideline of 0.1 *mSv* for the total dose from all radionuclides in the water supply.

Note: This example consists of fictitious data.

Before Proceeding Further

Chemicals

- Have all pathways of exposure been identified?
- Have the daily intakes from all pathways of exposure been calculated?
- Have the EDIs been estimated by adding up the exposures calculated from each pathway?
- Have the EDIs been compared to the TDI or RsD, if they are known for those contaminants?

Ionizing Radiation

- Have all pathways of exposure been identified?
- Have the estimated committed doses from all pathways of exposure been calculated?
- Has the total ED been estimated by adding up the exposures calculated from each pathway, including radiation from sources external to the body?
- Has the total ED been compared to the 1 *mSv* dose limit and has the dose from the drinking water pathway been compared to the 0.1 *mSv* guideline? Are exposures as low as reasonably achievable?

What's Next?

Once the exposure to a contaminant has been estimated and compared to the appropriate Tolerable Daily Intake (TDI), Risk-specific Dose (RsD), or the dose limit or drinking water guideline for radiation exposure, it is time to decide what action to take on the results. If the EDI is below the TDI or RsD, or if the radiation ED is below the dose limit or drinking water guideline, the risk to people's health may be considered small because the potential exposure to the contaminant is low. No further actions may be considered necessary. However, if the estimated exposures exceed the guidelines, the following options may be considered:

- Providing information to the public on how to minimize exposure. This could include advice on which changes in habits and lifestyle would reduce exposure;
- Recommending measures to reduce the release of the contaminants into the environment;

- Recommending voluntary standards for manufacturers; and
- Setting standards and guidelines at levels that protect human health.

The options considered will depend on the major pathway of exposure, the number or sensitivity of people exposed, and the possible interaction between different contaminants.

TABLE 1:

RECOMMENDED STANDARD VALUES FOR DAILY INTAKE OF AIR, WATER AND SOIL[1]

Age (years)	Air Inhalation (m^3/day)[2]	Water Ingestion[3] (L/day)	Soil Ingestion (mg/day)	Total Soil Adhered[4] (mg/day)
0 - < 0.5	2	BF: 0/0 NBF: 0.2/0.75	35	2,200
0.5 - < 5	5	0.2/0.8	50	3,500
5 - < 12	12	0.3/0.9	35	5,800
12 - < 20	21	0.5/1.3	20	9,100
20 +	23	0.4/1.5	20	8,700

[1] From: Health Canada. *Human Health Risk Assessment for Priority Substances*, 1994.

[2] 1,000 litres = 1 m^3

[3] For each age group, the amount of water a person drinks is shown with two values. The first value is straight tapwater, and the second value is straight tapwater plus tapwater-based beverages such as tea, coffee, and reconstituted soft drinks.

Exclusively breast fed infants (BF) do not require additional liquids. Estimates for non-breast-fed infants (NBF) are based on volume consumed as drinking water, and on drinking of 750 mL/day of formula made from powdered formula and tapwater for total drinking water.

[4] Estimated from the total body surface area for each age group (see TABLE 2); the proportion of the total body surface area exposed to soil is estimated at 30% for ages below 12 years, 28% for ages 12-19, and 24% for ages 20 and older; and approximately 2 mg of soil is estimated to adhere to each square centimetre of exposed skin.

TABLE 2:

RECOMMENDED STANDARD VALUES FOR BODY WEIGHT AND BODY SURFACE AREA

Body Weight and Body Surface Area Standard Values								
Age (years)	Body Weight[1] (kg)	Total Body Surface Area[2] (cm^2)	Head Surface Area[3] (cm^2)	Trunk Surface Area[3] (cm^2)	Arms Surface Area[3] (cm^2)	Hands Surface Area[3] (cm^2)	Legs Surface Area[3] (cm^2)	Feet Surface Area[3] (cm^2)
0 - < 0.5	7	3,680	660	1,325	520	185	770	220
0.5 - < 5	13	5,780	870	2,020	750	350	1,390	400
5 - < 12	27	9,660	1,210	3,330	1,210	480	2,705	725
12 - < 20	57	16,200	1,460	5,350	2,270	810	5,180	1,130
20+	70	18,200	1,275	6,370	2,550	910	5,820	1,275

[1] From: Health Canada. *Human Health Risk Assessment for Priority Substances*, 1994.

[2] Total Body Surface Area was derived using body height (centimetres) and weight (kilograms) data from the Canada Fitness Survey and the Nutrition Canada Survey and the following formula:

Total Body Surface Area (cm^2) = $0.2035 \times Weight^{0.51468} \times Height^{0.42246}$

[3] Surface Areas for each body part were determined as percentages of the Total Body Surface Area. The percentages were adapted from the *EPA Exposure Handbook*, 1989.

TABLE 3:

AVERAGE AMOUNTS OF VARIOUS FOOD GROUPS EATEN BY CANADIANS, FROM THE NUTRITION CANADA SURVEY

	Amount Eaten (grams/person/day)				
FOOD GROUP[1]	0 - < 0.5 yr[2]	0.5 - < 5 yr	5 - < 12 yr	12 - < 19 yr	20 +
DAIRY PRODUCTS	545	670	609	573	283
MEAT, POULTRY, FISH, EGGS	37	90	120	169	183
CEREAL PRODUCTS	53	168	300	325	247
FRUIT AND FRUIT PRODUCTS	112	189	202	160	186
VEGETABLES	42	125	198	250	250
FATS	0.8	11	21	29	25
NUTS AND DRIED LEGUMES	0.2	6	13	19	12
FOOD, PRIMARILY SUGAR	25	46	57	57	57
MIXED DISHES AND SOUPS	5	71	82	89	100
SOFT DRINKS, ALCOHOL	2	102	196	264	255

[1] Food groups have been derived from individual food composites (refer to Source below for details).

[2] These values are used if it is assumed that the infant is not exclusively breast-fed or not exclusively formula-fed.

Source: Health Canada. *Human Health Risk Assessment for Priority Substances*, 1994.

TABLE 4:

PERMEABILITY CONSTANTS (P) FOR SELECTED COMPOUNDS, WATER SKIN EXPOSURE

Compound	Permeability Constant (cm/hr)
Aniline	4.1×10^{-2}
Benzene	1.11×10^{-1}
Butanol	2.5×10^{-3}
2-Butanone (Methyl ethyl ketone)	5.0×10^{-3}
Carbon disulfide	5.3×10^{-1}
p-Chlorophenol	3.63×10^{-2}
p-Cresol	1.75×10^{-2}
Cobaltous chloride	5.5×10^{-4}
Dibutyl phthalate	2.3×10^{-4}
Ethanol	8.0×10^{-4}
Ethylbenzene	1.37
Mercuric chloride	1.33×10^{-3}
Methanol	5.0×10^{-4}
Nonanol	6.0×10^{-2}
Parathion	1.0×10^{-2}
Phenol	8.22×10^{-3}
Styrene	6.7×10^{-1}
Toluene	1.01
3,4-Xylenol	3.6×10^{-2}

Note: The most cautious approach is to use a permeability constant of 1.0 cm/hr in the calculations. This is done by a number of agencies rather than using measured or estimated values.

Source: EPA. *Interim Guidance for Dermal Exposure Assessment.* OHEA-E-367, October, 1990.

TABLE 5:

BIOAVAILABILITY FACTORS (BF) FOR SELECTED COMPOUNDS, SOIL SKIN EXPOSURE

Compound	Bioavailability Factor (unitless)
Benzo [a] pyrene	0.01
Benzene	0.47
DDT	0.03
TCDD (Dioxin)	0.01
Toluene	0.55
m-Xylene	1.0

Note: The above bioavailability factors are approximate values only, and may differ from bioavailability factors used by others. The most cautious approach is to use a bioavailability factor of 1.0 in the calculations. This is done by a number of agencies rather than using measured or estimated values.

Source: EPA. *Interim Guidance for Dermal Exposure Assessment*, OHEA-E-367, 1990.

TABLE 6:

TOLERABLE DAILY INTAKES AND RISK-SPECIFIC DOSES FOR SELECTED CONTAMINANTS

Non-Carcinogen	Tolerable Daily Intake	Reference*
Copper	0.05 - 0.5 mg/kg/day	1
Endrin	1.0 µg/kg/day	2
Lead	(infants & adults) = 3.57 µg/kg/day	1
Mirex	0.028 µg/kg/day	2
Mercury: Methyl Hg Total Hg (methyl Hg + inorganic Hg)	0.47 µg/kg/day 0.71 µg/kg/day	1
Tin	2 mg/kg/day	1
Zinc	0.3 - 1.0 mg/kg/day	1

Carcinogen**	Slope Factor*** $(mg/kg/day)^{-1}$	RsD (mg/kg/day) (1 x 10^{-6} risk level)
Aldrin	17.0	5.8×10^{-7}
Benzene	0.029	3.4×10^{-4}
Benzo[a]Pyrene	7.3	1.3×10^{-6}
Chlordane	1.3	7.7×10^{-6}
Carbon Tetrachloride	0.13	7.7×10^{-5}
p,p-DDT, p,p-DDE p,p-DDD	0.34	2.9×10^{-5}
Dieldrin	16.0	6.2×10^{-7}
Heptachlor	4.5	2.2×10^{-6}
Heptachlor Epoxide	9.1	1.1×10^{-6}
Hexachlorobenzene	1.6	6.2×10^{-6}
Hexachlorocyclohexanes (α-HCH)	6.3	1.6×10^{-6}
Pentachlorophenol	0.12	8.3×10^{-5}
Polychlorinated Biphenyl (PCB)	7.7	1.3×10^{-6}

* References: 1 - Joint European Committee on Food Additives
2 - Toxicological Evaluation Division, Health Canada

** Known or probable carcinogen

*** Slope Factors obtained from the IRIS Database.

TABLE 7

DOSE CONVERSION FACTORS (DCFs) FOR SELECTED RADIONUCLIDES (United Kingdom National Radiological Protection Board, 1991)

Radionuclide	Dose Conversion Factors for Inhalation and Ingestion (*Sv/Bq*)			
	Inhalation		Ingestion	
	Children (1 yr)	Adult (18+ yrs)	Children (1 yr)	Adult (18+ yrs)
Tritium (^{3}H)	4.30×10^{-11}	1.80×10^{-11}	4.30×10^{-11}	1.80×10^{-11}
Carbon-14 (^{14}C)	1.50×10^{-9}	5.60×10^{-10}	1.50×10^{-9}	5.60×10^{-10}
Strontium-90 (^{90}Sr)	1.60×10^{-6}	3.50×10^{-7}	1.20×10^{-7}	2.80×10^{-8}
Iodine-129 (^{129}I)	1.40×10^{-7}	6.70×10^{-8}	2.20×10^{-7}	1.10×10^{-7}
Iodine-131 (^{131}I)	1.10×10^{-7}	1.30×10^{-8}	1.80×10^{-7}	2.20×10^{-8}
Cesium-137 (^{137}Cs)	7.00×10^{-9}	8.50×10^{-9}	1.00×10^{-8}	1.30×10^{-8}
Radium-226 (^{226}Ra)	1.40×10^{-5}	2.10×10^{-6}	9.10×10^{-7}	2.20×10^{-7}
Uranium-234 (^{234}U)	1.50×10^{-4}	3.50×10^{-5}	1.70×10^{-7}	3.90×10^{-8}
Uranium-238 (^{238}U)	1.30×10^{-4}	3.10×10^{-5}	1.50×10^{-7}	3.60×10^{-8}
Plutonium-239 (^{239}Pu)	2.00×10^{-4}	6.80×10^{-5}	1.20×10^{-6}	5.60×10^{-7}
Americium-241 (^{241}Am)	1.60×10^{-4}	7.00×10^{-5}	1.30×10^{-6}	5.70×10^{-7}

Dose Conversion Factor (DCF): The committed effective dose resulting from the inhalation or ingestion of 1 *Bq* of a given radionuclide. Unit - sievert per becquerel (*Sv/Bq*).

TABLE 8:

INTERIM ASSESSMENT CRITERIA FOR SOIL AND WATER

	Soil	Water
General Parameters		
pH	6 to 8	—
conductivity	2 dS/m	—
sodium adsorption ratio	5	—
Inorganic Parameters		
antimony	20[1]	—
arsenic	5	5
barium	200	50
beryllium	4	—
boron (hot water soluble)	1	—
cadmium	0.5	1
chromium(+6)	2.5	—
chromium (total)	20	15
cobalt	10	10
copper	30	25
cyanide (free)	0.25	40
cyanide (total)	2.5	40
fluoride (total)	200	—
lead	25	10
mercury	0.1	0.1
molybdenum	2	5
nickel	20	10
selenium	1	1
silver	2	5
sulphur (elemental)	250	—
thallium	0.5	—
tin	5	10
vanadium	25	—
zinc	60	50

Notes: all values in µg/g dry weight or µg/L unless otherwise stated.

Interim assessment criteria are largely based on ambient or background concentrations for most general and inorganic parameters and on analytical detection limits for most organic parameters.

— value not established.

See end of table for numbered footnotes.

Source: Canadian Council of Ministers of the Environment. *Interim Canadian Environmental Quality Criteria for Contaminated Sites*, Report CCME EPC-CS34, September, 1991.

INTERIM ASSESSMENT AND CRITERIA FOR SOIL AND WATER (continued)

	Soil	Water
Monocyclic Aromatic Hydrocarbons		
benzene	0.05	0.5
chlorobenzene	0.1	0.1
1,2-dichlorobenzene	0.1	0.2
1,3-dichlorobenzene	0.1	0.2
1,4-dichlorobenzene	0.1	0.2
ethylbenzene	0.1	0.5
styrene	0.1	0.5
toluene	0.1	0.5
xylene	0.1	0.5
Phenolic Compounds		
non-chlorinated[2] (each)	0.1	0.1
chlorophenols[3] (each)	0.05	1.0
Polycyclic Aromatic Hydrocarbons (PAHs)		
benzo(a)anthracene	0.1	0.01
benzo(a)pyrene	0.1	0.01
benzo(b)fluoranthene	0.1	0.01
benzo(k)fluoranthene	0.1	0.01
dibenz(a,h)anthracene	0.1	0.01
indeno(1,2,3-c,d)pyrene	0.1	0.1
naphthalene	0.1	0.2
phenanthrene	0.1	0.2
pyrene	0.1	0.2
Chlorinated Hydrocarbons		
chlorinated aliphatics[4] (each)	0.1	0.1
chlorobenzenes[5] (each)	0.05	0.3
hexachlorobenzene	0.1	0.1
hexachlorocyclohexane	0.01	—
PCBs[6]	0.1	0.1
PCDDs and PCDFs[7]	0.00001	—
Miscellaneous Organic Parameters		
non-chlorinated aliphatics (each)	0.3	—
phthalic acid esters (each)	30	—
quinoline	0.1	—
thiophene	0.1	—

Table 8 footnotes

[1] Set equal to the Agricultural Remediation Criteria value

[2] Non-chlorinated phenolic compounds include:
2,4-dimethylphenol
2,4-dinitrophenol
2-methyl 4,6-dinitrophenol
nitrophenol (2-, 4-)
phenol
cresol

[3] Chlorophenols include:
chlorophenol isomers (ortho, meta, para)
dichlorophenols (2,6- 2,5- 2,4- 3,5- 2,3 3,4
trichlorophenols (2,4,6- 2,3,6- 2,4,5- 2,3,5- 2,3,4- 3,4,5-)
tetrachlorophenols (2,3,5,6- 2,3,4,5- 2,3,4,6-)
pentachlorophenol

[4] Aliphatic chlorinated hydrocarbons include:
chloroform
dichloroethane (1,1- 1,2-), dichloroethene (1,1- 1,2-)
dichloromethane
1,2-dichloropropane, 1,2-dichloropropene (cis and trans)
1,1,2,2-tetrachloroethane, tetrachloroethene
carbon tetrachloride
trichloroethane (1,1,1- 1,1,2-), trichloroethene

[5] Chlorobenzenes include
all trichlorobenzene isomers
all tetrachlorobenzene isomers
pentachlorobenzene

[6] PCBs include mixtures 1242, 1248, 1254, and 1260

[7] PCDDs and PCDFs expressed in 2,3,7,8-TCDD equivalents. NATO International Toxicity Equivalency Factors (I-TEFs) for congeners and isomers of PCDDs and PCDFs are as follows:

Congener	TEF	Congener	TEF
2,3,7,8-T_4CDD	1.0	2,3,7,8-T_4CDF	0.1
1,2,3,4,8-P_5CDD	0.5	2,3,4,7,8-P_5CDF	0.5
1,2,3,4,7,8-H_6CDD	0.1	1,2,3,7,8-P_5CDF	0.05
1,2,3,7,8,9-H_6CDD	0.1	1,2,3,4,7,8-H_6CDF	0.1
1,2,3,6,7,8-H_6CDD	0.1	1,2,3,7,8,9-H_6CDF	0.1
1,2,3,4,6,7,8-H_7CDD	0.1	1,2,3,6,7,8-H_6CDF	0.1
O_8CDD	0.001	2,3,4,6,7,8-H_6CDF	0.1
		1,2,3,4,6,7,8-H_7CDF	0.1
		1,2,3,4,7,8,9-H_7CDF	0.01
		O_8CDF	0.001

GLOSSARY

Becquerel	The becquerel (*Bq*) is the International System (S.I.) unit for measuring the activity, or radioactive decay, of a radionuclide. A becquerel is defined as one atomic disintegration per second.
Bioavailability factor	A pollutant or other chemical is in a physical or chemical form that permits it to be eaten, breathed, or otherwise absorbed by living things. This is known as the bioavailability of a substance. The bioavailability factor simply estimates the proportion of the substance in the environment that is available to be absorbed. For example, a bioavailability factor of 0.5 means that 50% of the substance in the environment is available to be absorbed. The bioavailability factor is unknown for many compounds. In these cases it is assumed the bioavailability factor is 1.0 (i.e., 100% of the substance in the environment is available for absorption).
Committed dose	The radiation dose, corrected for type of radiation and type of tissue or organ exposed, that will be received over a period of time following a single intake of radioactive material into the body. Standard periods of integration are 50 years for adults and 70 years for children.
Estimated daily intake	The sum of all exposures of a substance from all the pathways of exposure is the Estimated Daily Intake (EDI). This is usually expressed in milligrams of contaminant per kilogram of body weight per day (mg/kg/day).
Exposure	Exposure is any contact between a substance and an individual. Exposure may occur by different means, including eating, drinking, breathing, and skin contact.
Exposure factor	The exposure factor reflects how often a person is exposed to a contaminant averaged over a lifetime. It is calculated by multiplying the exposure frequency (events/year) and the exposure duration (years/lifetime).
Exposure pathway	The pathway a contaminant may take to reach humans or other living organisms. Exposure pathways include all the elements that link the source of a contaminant to the exposure route (ingestion, inhalation, skin contact) by which the contaminant enters the body.
Exposure route	An exposure route is how a contaminant enters the human body. There are three general routes by which humans may take contaminants into their bodies. These include eating and drinking (ingestion), inhalation, and absorption through the skin.
Inorganic chemicals	Inorganic chemicals are mineral in origin. Examples of inorganic substances are lead, cadmium, mercury, and asbestos.
Irradiation	Exposure to ionizing radiation.
Organic chemicals	Organic chemicals contain carbon, usually in combination with other elements such as hydrogen, oxygen, nitrogen or chlorine. Vegetable matter, petroleum, and plastics are examples of organic materials, as are PCBs, DDT, and polyvinyl chloride.

Permeability constant	The permeability constant describes the speed at which a chemical passes through the skin into the body. It is usually determined from laboratory studies and is expressed in cm/hour.
Radionuclide	An unstable nuclide (nucleus of an atom) that undergoes spontaneous radioactive decay, emitting ionizing radiation as it does so, and changing eventually from one element into another.
Sievert	The sievert (*Sv*) is the International System (S.I.) unit for radiation effective dose, equal to 1 joule of energy absorbed per kilogram of absorbing tissue.
Tolerable Daily Intake	The tolerable daily intake (TDI) is the quantity of a chemical that humans can consume on a daily basis, for a lifetime, with reasonable assurance that their health will not be threatened. It is usually expressed in milligrams of chemical per kilogram of body weight per day (mg/kg/day).

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RESOURCES AND CONTACTS

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Atmospheric Environment Service
Environment Canada
25 St. Clair Avenue East, Third Floor
Toronto, Ontario M4T 1M2
Tel: (416) 973-1114

Great Lakes Health Effects Program
Health Canada
Main Building, Room 1108
Tunney's Pasture, 0301 A1
Ottawa, Ontario K1A 0K9
Tel: (613) 957-1876

Food Directorate
Health Canada
Health Protection Building
Tunney's Pasture
Ottawa, Ontario K1A 0L2
Tel: (613) 957-1821

Monitoring and Criteria Division (Hazardous Wastes)
Health Canada
Room 126, Environmental Health Centre
Tunney's Pasture
Ottawa, Ontario K1A 0L2
Tel: (613) 957-3128

Environmental Radiation Hazards Division
Radiation Protection Bureau
Health Canada
775 Brookfield Road, Confederation Heights
Ottawa, Ontario K1A 1C1
Tel: (613) 954-6671

Pesticides Information Division
Agriculture and Agri-Food Canada
59 Camelot Drive
Nepean, Ontario K1A 0Y9
Tel: 1-800-267-6315 (Pesticides Information Call-Line)

Workplace Hazardous Materials Information Systems (WHMIS)
Product Safety Bureau
Health Canada
17th floor, Zone 2
Place du Portage, Phase 1
50 Victoria Street
Hull, Quebec K1A 0C9
Tel: (819) 953-2035

2. Provincial Government (Ontario)

Environmental Health and Toxicology Unit
Ontario Ministry of Health
5700 Yonge Street, Eighth Floor
North York, Ontario M2M 4K2
Tel: (416) 327-7427

Great Lakes Section
Ontario Ministry of Environment and Energy
125 Resources Road
Etobicoke, Ontario M9P 3V6
Tel: (416) 235-6222

Hazardous Contaminants Coordination Branch
Ontario Ministry of Environment and Energy
135 St. Clair Avenue West
Toronto, Ontario M4V 1P5
Tel: (416) 323-5095

Ontario Ministry of Environment and Energy
Public Inquiries Centre
135 St. Clair Avenue West, 1st floor
Toronto, Ontario M4V 1P5
Tel: (416) 323-4231 or 1-800-565-4923

Ontario Ministry of Natural Resources
Public Information Centre
900 Bay Street, Room 1-M73
2 McDonald Block
Toronto, Ontario M7A 2C1
Tel: (416) 314-2000

3. Municipal Government

Local Commissioner of Planning and Public Works

Address: _____ Address: _____

_____ _____

_____ _____

Tel: _____ Tel: _____

Local Environment Office

Address: _____ Address: _____

_____ _____

_____ _____

Tel: _____ Tel: _____

Local Sewage Treatment Plant

Address: _____ Address: _____

_____ _____

_____ _____

Tel: _____ Tel: _____

Other Local Contacts

Address: _____ Address: _____

_____ _____

_____ _____

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University of Western Ontario
Faculty of Medicine
Department of Family Medicine
Kresge Building, Room K101
London, Ontario N6A 5C1
Tel: (519) 661-2037

5. Agencies and Associations

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Department of Health and Human Services
1600 Clifton Road
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Tel: (404) 639-6206

Canadian Centre for Occupational Health and Safety
250 Main Street East
Hamilton, Ontario L8N 1H6
Tel: (1-800) 263-8466

Canadian Institute of Public Health Inspectors
38 Auriga Drive, Suite 201
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Canadian Public Health Association
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International Commission on Radiological Protection (ICRP)
The documents of ICRP are published as the *Annals of ICRP* and are available from:
Review Journals
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U.S. National Technical Information Service
U.S. Department of Commerce
Springfield, Virginia 22161 USA
Tel: (703) 487-4650

ON-LINE DATABASES

These databases are on computer. To be able to use them, you will need a computer that can communicate with the main database computer. Some public libraries and most university libraries have the necessary equipment and connections to search at least some of these databases for you. For the very scientific databases, the university libraries are better able to handle your information needs. If they cannot do the search, librarians can usually find out who can. For assistance with health statistics databases, try the Medical Officer of Health and the Ontario Ministry of Health.

Most searches will cost money. The more specific you can be about the information you need, the shorter the search and the lower the cost. Again, librarians usually have good ideas on how to reduce your costs.

Database Name	Description
Biosis Previews	Contains citations from Biological Abstracts.
Cab Abstracts	A comprehensive file of agricultural and biological information.
CA Search	Contains bibliographic data, keyword phrases and index entries for all documents covered by the Chemical Abstracts Services.
Chemical Safety Newsbase	Information on the hazardous and potentially hazardous effects of chemicals and processes encountered by workers in industry and laboratories. It also covers microbiological and radiation hazards encountered in the workplace.
CRIS/USDA	Information on U.S. federal- and state-supported research in agriculture, food and nutrition, forestry and related fields.
Drug Information Fulltext	Information on stability, chemistry and phamacokinetics of drugs, as well as on their action, use, dosage, and administration. The file also covers compatibility and interactions of drugs and cautions of use.
EiCompendex Plus	Contains abstracts from the world's significant literature of engineering and technology.
EMBASE	Contains abstracts and citations of articles on human medicine and drugs.
Enviroline	Contains index and abstract coverage of literature on all aspects of the environment.
Environmental Bibliography	Covers fields of general human ecology, atmospheric studies, energy, land resources, water resources, nutrition and health.
International Pharmaceutical Abstracts	Information on all phases of development and use of drugs and on professional pharmaceutical practice.
IRIS	The Integrated Risk Information System (IRIS) registry contains toxicological and regulatory information on more than 400 chemicals with more added to the database each year.

Database Name	Description
MEDLINE/MEDLARS	Covers articles on every aspect of biomedicine.
Pollution Abstracts	References to environment-related literature on pollution, its sources and its control.
NIOSHTIC	Covers all aspects of occupational safety and health.
NTIS	Contains results of U.S. government-sponsored research, development and engineering.
RTECS	The Registry of Toxic Effects of Chemical Substances(RTECS) contains toxicity data for over 100,000 chemical substances.
Sedbase	Full text database that critically analyses the published drug side effect literature on drugs currently in use.
Toxline	Covers the adverse effects of chemicals, drugs and physical agents on living systems.